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Annual Streamflow Summaries From Four Subalpine Watersheds In Colorado

by Charles F. Leaf
and Glen E. Brink

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USDA Forest Service
General Technical Report RM-1

December 1972

Rocky Mountain Forest and
Range Experiment Station

Forest Service
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Abstract

Streamflow runoff summaries are presented for four experimental watersheds near Fraser and Steamboat Springs, Colorado. Interval of published record varies from 1943-71 at Fraser to 1967-71 at Steamboat Springs.

Keywords: Demonstration watersheds, Fraser Experimental Forest, snowmelt, streamflow, subalpine watersheds, surface waters.

ABOUT THE COVER:

Cipolletti weir on the 3.4-square-mile South Soda Creek watershed in the Routt National Forest near Steamboat Springs, Colorado. The steel deck on the weir ponds is necessary since winter snow in the Park Range often accumulates to depths exceeding 10 feet. This weir is designed to measure a peak flow of 225 cubic feet per second.

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Annual Streamflow Summaries from Four Subalpine Watersheds in Colorado[1]

by

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and title page? Imperfect volumes delay return of binding. Thanks.
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[1] *Research reported here was conducted and partly financed in cooperation with the Division of Atmospheric Water Resources Management, Bureau of Reclamation, U. S. Department of the Interior.*

[2] *Central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

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Annual Streamflow Summaries from Four Subalpine Watersheds in Colorado

Charles F. Leaf and Glen E. Brink

This paper contains computer-generated streamflow runoff summaries from four small subalpine watersheds near Fraser and Steamboat Springs, Colorado (see maps, figs. 1 and 2). Runoff from each watershed is gaged from early spring prior to snowmelt until late fall. The data are processed in FORTRAN IV computer language on Control Data Corporation's (CDC) 6400 computer[3] currently in use at the Colorado State University Computer Center in Fort Collins.

Fraser Experimental Forest

Annual summaries of daily runoff from the 1,984-acre East St. Louis Creek watershed are given for the 1943-71 period of record. Map coordinates for the basin are 39°54' north latitude and 105°53' west longitude. Elevations range from 9,500 feet m.s.l. at the stream gage to 12,763 feet. Approximately one-third of East St. Louis Creek is above timberline and two-thirds is forested. Retzer[4] described the forest cover, geology, and soil; Haeffner[5] summarized a 33-year record of precipitation and temperature in the area.

Steamboat Springs (Park Range)

Runoff data from three watersheds in the Park Range are summarized for the 1967-71 period of record. They include:

A. West Walton Creek: 849 acres, 9,100-9,728 feet m.s.l., 40°22'35'' latitude, and 106°42'30'' longitude.

B. North Fish Creek: 1,435 acres, 9,800-10,724 feet m.s.l., 40°32'25'' latitude, 106°44' longitude.

C. South Soda Creek: 2,174 acres, 8,300-10,724 feet m.s.l., 40°32'30'' latitude, 106°45' longitude.

These data were obtained in cooperation with the Division of Atmospheric Water Resources Management, Bureau of Reclamation, U. S. Department of the Interior, as part of weather modification studies in the Park Range.

Instrumentation and Data Reduction

All gaging stations are Cipolletti weirs[6] which are serviced at weekly intervals during the runoff season. From the continuous record of gage height, streamflow volumes can be computed by means of rating equations for any desired time interval. Laboratory-derived rating

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[3] *The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U. S. Department of Agriculture to the exclusion of others that may be suitable.*

[4] *Retzer, J. L. Soil survey of Fraser alpine area, Colorado. U. S. Dep. Agric. and Colo. Agric. Exp. Stn. Ser. 1956, No. 20, 47 p. Wash. D.C.: Gov. Print. Off. 1962.*

[5] *Haeffner, Arden D. Daily temperatures and precipitation for subalpine forest, central Colorado. USDA For. Serv. Res. Pap. RM-80, 48 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 1971.*

[6] *The Cipoletti weir on East St. Louis Creek has operated since the 1964 snowmelt runoff season. Prior to this time, flows were gaged by a trapezoidal flume which was rated in place with a velocity head rod.*

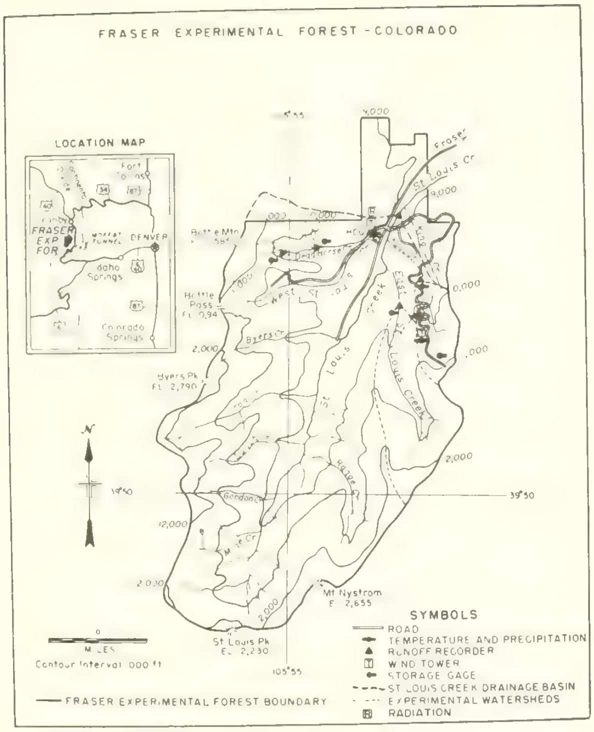

Figure 1.—Location map for East St. Louis Creek, Fraser Experimental Forest.

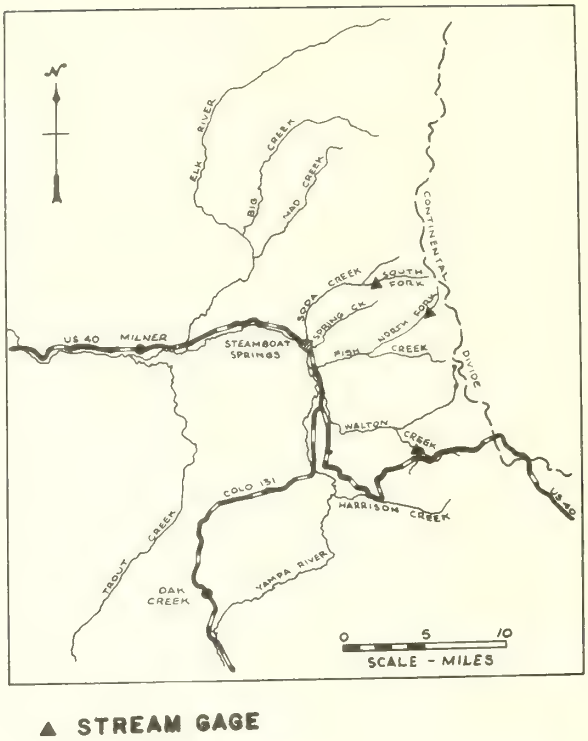

Figure 2.—Location map for Park Range watersheds, near Steamboat Springs.

equations are used to compute stream discharge.[7]

Gage heights are logged on FW-1 strip-chart recorders and Fischer-Porter ADR punched-tape recorders programed to punch at 15-minute intervals. At the present time (1972), the strip-chart recorders serve only as backup systems for the Fischer-Porters. Both charts and punched tapes are analyzed essentially according to procedures described by Johnson and Dils.[8]

Automatic Data Processing

The following tables are one-page summaries of the daily streamflow in acre-feet for the period of record. Additional information printed at the bottom of each summary table for each month and for the period of record includes:

1. Total flow in acre-feet
2. Equivalent depth in inches over the whole watershed
3. Maximum daily flow in acre-feet
4. Minimum daily flow (for months only), in acre-feet
5. Equivalent c.f.s. for the seasonal peak daily flow.

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[7] *King, H. A. Handbook of hydraulics. Ed. 4. 556 p. N.Y.: McGraw-Hill Co. 1954.*

[8] *Johnson, E. A., and R. W. Dils. Outline for compiling precipitation, runoff, and ground water data from small watersheds. U.S. Dep. Agric., For. Serv., Southeast. For. Exp. Stn., Stn. Pap. 68, 40 p. Asheville, N.C. 1956.*

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1943

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1				1.515	9.288	24.981	41.474	11.670	6.087				1
2				1.538	10.775	28.724	38.047	11.482	5.979				2
3				1.564	11.172	22.630	35.616	10.995	5.987				3
4				1.589	11.002	20.175	33.153	10.791	5.796				4
5				1.639	9.428	20.053	31.492	10.699	5.879				5
6				1.664	8.477	21.067	29.840	10.219	5.664				6
7				1.671	7.337	24.303	28.891	10.003	5.447				7
8				1.651	6.669	29.419	27.768	10.025	5.150				8
9				1.614	6.294	37.206	26.088	9.521	4.995				9
10				1.589	6.244	39.149	24.092	9.187	4.843				10
11				1.564	6.714	38.630	22.272	9.088	4.467				11
12				1.539	6.644	34.655	20.959	8.471	4.355				12
13				1.515	6.524	34.471	20.295	7.963	4.285				13
14				1.500	6.625	34.398	19.111	7.601	4.211				14
15				1.539	6.570	33.733	17.734	6.730	4.300				15
16				1.589	6.221	32.770	17.257	9.595	4.188				16
17				1.614	6.000	35.733	16.458	9.138	4.351				17
18				1.639	5.735	38.732	15.861	8.755	4.411				18
19				1.808	5.304	40.920	16.018	8.366	4.500				19
20				1.996	5.128	45.384	15.904	7.369	4.372				20
21				2.210	5.140	49.686	15.893	7.230	4.427				21
22				2.643	5.127	52.905	16.804	6.938	4.311				22
23				2.695	5.617	52.904	15.262	7.159	4.254				23
24				3.155	6.546	50.582	14.214	8.472	4.164				24
25				3.576	7.161	50.586	12.891	8.026	3.967				25
26				3.769	8.172	49.319	12.347	6.732	4.042				26
27				3.405	10.600	47.352	12.780	6.511	4.003				27
28				3.898	15.401	46.209	12.001	6.390	3.909				28
29				5.182	18.179	46.566	11.764	6.325	2.262				29
30				7.190	24.715	46.285	14.188	6.465					30
31			.527		21.254		14.136	6.446					31
TOTAL													
A-F			.527	70.072	276.077	1129.539	650.624	264.374	134.620				ACRE FEET
INS			.003	.423	1.669	6.831	3.935	1.599	.814				INCHES
FLOW													
MAX			.527	7.190	24.715	52.905	41.474	11.670	6.087				MAXIMUM
MIN			.000	1.500	5.127	20.053	11.764	6.325	.000				MINIMUM

TOTAL SEASONAL RUNOFF 2525.836 ACRE FEET, 15.277 INCHES
SEASONAL PEAK DAILY FLOW 52.906 ACRE FEET, 26.673 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1944

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1				.651	1.843	21.802	27.552	8.554	4.556				1
2				1.843	1.843	23.166	27.000	7.500	4.506				2
3				1.843	1.843	25.596	25.589	6.980	4.486				3
4				1.843	1.843	25.680	23.712	6.633	4.436				4
5				1.843	1.843	27.573	22.856	6.459	4.419				5
6				1.843	1.896	28.335	22.100	6.347	4.355				6
7				1.843	2.056	30.331	20.344	6.210	4.323				7
8				1.843	2.220	32.551	19.159	6.091	4.242				8
9				1.843	2.361	34.319	18.663	6.390	4.150				9
10				1.843	2.504	35.088	17.906	6.223	4.185				10
11				1.843	2.679	35.784	17.512	6.114	4.199				11
12				1.843	3.419	36.637	16.181	6.064	4.228				12
13				1.843	4.876	35.994	14.855	5.855	4.154				13
14				1.843	6.165	40.110	14.350	5.743	4.077				14
15				1.843	7.032	43.738	14.367	5.851	4.148				15
16				1.843	9.388	43.103	13.598	5.902	4.114				16
17				1.843	7.870	35.099	13.039	5.772	4.127				17
18				1.843	5.289	41.975	12.566	6.022	4.071				18
19				1.843	5.071	44.171	12.869	6.470	4.091				19
20				1.843	5.518	49.585	12.482	5.816	4.001				20
21				1.843	6.026	51.668	11.444	5.626	3.911				21
22				1.843	8.265	46.438	10.677	5.657	3.906				22
23				1.843	11.069	41.982	10.193	5.547	3.940				23
24				1.843	12.207	43.009	11.123	5.630	3.953				24
25				1.843	11.727	41.980	10.785	5.668	3.894				25
26				1.843	10.744	39.016	10.046	5.124	3.942				26
27				1.843	10.221	34.663	9.595	4.913	3.361				27
28				1.843	12.907	33.641	8.867	4.857	1.186				28
29				1.843	14.717	31.871	8.852	4.838	1.186				29
30				1.843	18.397	29.387	8.601	4.838	1.186				30
31					20.782		8.626	4.663					31
TOTAL													
A-F				54.122	214.637	1084.305	475.521	184.372	115.345				ACRE FEET
INS				.327	1.298	6.558	2.876	1.115	.697				INCHES
FLOW													
MAX				1.843	20.782	51.668	27.552	8.554	4.556				MAXIMUM
MIN				.651	1.843	21.802	8.601	4.663	1.186				MINIMUM

TOTAL SEASONAL RUNOFF 2128.306 ACRE FEET, 12.873 INCHES
SEASONAL PEAK DAILY FLOW 51.669 ACRE FEET, 26.049 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1945

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1				1.186	1.186	14.639	35.163	25.285	7.643				1
2				1.186	1.186	13.369	36.119	22.178	7.754				2
3				1.186	1.186	13.896	34.923	25.719	6.995				3
4				1.186	2.750	15.197	33.034	27.123	6.501				4
5				1.186	3.492	18.661	31.785	26.114	6.094				5
6				1.186	3.438	20.119	32.549	26.244	5.368				6
7				1.186	3.418	21.326	32.433	27.370	5.422				7
8				1.186	3.670	20.803	31.153	27.071	5.142				8
9				1.186	3.830	19.335	30.601	45.388	5.316				9
10				1.186	4.213	18.172	31.042	22.597	5.302				10
11				1.186	4.501	18.487	29.967	21.256	5.398				11
12				1.186	4.180	22.000	28.897	21.405	5.438				12
13				1.186	4.999	30.984	27.756	21.135	5.292				13
14				1.186	5.000	36.992	26.437	19.486	5.420				14
15				1.186	4.214	32.917	25.367	18.390	5.480				15
16				1.186	3.936	25.696	25.587	17.227	5.003				16
17				1.186	4.458	24.869	23.983	16.359	4.954				17
18				1.186	5.640	26.885	22.982	16.894	5.137				18
19				1.186	6.218	29.861	24.183	16.190	5.270				19
20				1.186	6.187	30.812	23.971	16.059	5.531				20
21				1.186	5.629	34.173	21.868	16.036	5.702				21
22				1.186	4.971	48.373	22.818	13.988	5.916				22
23				1.186	5.110	48.040	24.732	12.941	6.047				23
24				1.186	6.420	53.502	24.592	12.267	5.955				24
25				1.186	8.228	54.282	22.273	11.825	6.107				25
26				1.186	11.584	50.745	20.199	12.266	6.048				26
27				1.186	14.089	47.526	19.212	11.199	4.915				27
28				1.186	15.899	44.494	18.347	10.128	1.186				28
29				1.186	17.343	37.718	21.367	9.997	1.186				29
30				1.186	18.870	35.700	20.958	9.420	1.186				30
31			.411		17.379		23.655	8.347					31
TOTAL													
A-F			.411	35.589	203.236	909.588	827.971	587.917	158.723				ACRE FEET
INS			.002	.215	1.229	5.501	5.007	3.555	.960				INCHES
FLOW													
MAX			.411	1.186	18.870	54.282	36.119	45.388	7.754				MAXIMUM
MIN			.000	1.186	1.186	13.369	18.347	8.347	1.186				MINIMUM

TOTAL SEASONAL RUNOFF 2723.437 ACRE FEET, 16.472 INCHES
SEASONAL PEAK DAILY FLOW 54.283 ACRE FEET, 27.367 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1946

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1				1.186	1.186	9.658	20.320	7.651	5.648				1
2				1.186	4.926	9.775	19.116	7.285	5.538				2
3				1.186	6.414	13.130	18.471	6.984	5.337				3
4				1.186	6.919	21.020	17.555	6.573	5.138				4
5				1.186	7.682	29.556	17.716	6.386	5.029				5
6				1.186	8.106	30.501	17.370	6.431	4.983				6
7				1.186	8.717	42.249	16.492	6.281	4.945				7
8				1.186	9.959	43.828	16.359	6.067	4.836				8
9				1.186	11.566	44.956	15.329	5.955	4.820				9
10				1.186	11.048	47.314	14.669	5.983	4.787				10
11				1.186	9.322	47.134	14.117	6.429	4.941				11
12				1.186	9.002	45.723	13.839	7.157	4.841				12
13				1.186	8.968	43.462	15.011	6.800	5.104				13
14				1.186	8.825	42.239	15.731	6.144	4.743				14
15				1.186	8.946	42.766	13.256	6.028	4.816				15
16				1.186	8.813	42.462	12.397	5.934	4.752				16
17				2.138	8.300	45.341	11.990	5.705	4.619				17
18				1.186	8.365	44.316	11.289	5.569	5.343				18
19				1.186	8.214	36.986	10.890	5.395	5.469				19
20				1.186	8.313	32.675	10.235	5.457	4.995				20
21				1.186	8.568	29.089	9.206	5.461	4.769				21
22				1.186	9.044	28.050	8.780	6.049	4.860				22
23				1.186	9.084	27.724	8.657	7.054	4.808				23
24				1.186	8.604	26.515	8.509	6.830	4.831				24
25				1.186	8.987	25.433	9.041	6.277	4.716				25
26				1.186	10.147	24.884	8.490	5.989	4.628				26
27				1.186	12.870	24.361	7.995	5.759	4.577				27
28				1.186	12.965	23.236	8.009	5.768	4.496				28
29				1.186	11.461	22.239	8.276	6.717	4.513				29
30				1.186	10.444	21.678	8.612	5.738	2.042				30
31					9.881		8.097	5.417					31
TOTAL													
A-F				36.541	275.661	968.315	395.840	193.288	144.939				ACRE FEET
INS				.221	1.667	5.856	2.394	1.169	.876				INCHES
FLOW													
MAX				2.138	12.965	47.314	20.320	7.651	5.648				MAXIMUM
MIN				1.186	1.186	9.658	7.995	5.395	2.042				MINIMUM

TOTAL SEASONAL RUNOFF 2014.586 ACRE FEET, 12.185 INCHES
SEASONAL PEAK DAILY FLOW 47.314 ACRE FEET, 23.854 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1947

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					3.361	18.012	53.863	18.339	6.273				1
2					4.389	21.417	54.578	17.815	6.142				2
3					5.632	23.641	52.443	18.067	6.099				3
4					7.658	24.923	52.314	17.608	6.109				4
5					7.460	23.544	50.346	16.888	6.125				5
6					7.055	24.576	47.494	15.216	6.115				6
7					7.896	36.176	46.413	14.636	5.970				7
8					10.264	51.060	44.916	14.624	5.999				8
9					12.082	45.603	43.580	15.526	6.263				9
10					14.155	37.666	40.918	14.935	7.204				10
11					12.782	33.415	37.891	14.214	6.715				11
12					9.005	29.045	35.592	14.137	6.895				12
13					8.557	28.477	33.326	12.620	6.370				13
14					8.854	28.499	31.318	11.878	5.807				14
15					9.181	30.586	33.041	11.153	5.616				15
16					8.923	35.144	32.293	10.460	5.457				16
17					9.810	41.584	29.381	10.401	5.298				17
18					9.884	48.297	27.457	11.069	5.252				18
19					10.037	53.012	26.047	10.138	5.132				19
20					11.244	64.608	24.904	9.208	5.133				20
21					13.763	58.918	23.921	8.974	4.895				21
22					15.009	53.503	24.279	8.707	4.823				22
23				1.999	14.266	47.441	23.389	8.533	5.043				23
24				2.768	13.479	44.341	22.047	8.853	5.379				24
25				2.709	14.484	45.215	21.137	8.269	5.189				25
26				2.799	16.050	51.595	20.455	7.649					26
27				2.891	17.425	54.323	19.628	7.452					27
28				2.798	17.883	56.128	18.801	7.089					28
29				2.798	15.834	57.027	19.722	6.675					29
30				2.847	15.905	54.658	19.407	6.695					30
31					17.020		18.790	6.533					31
TOTAL													
A-F				21.612	349.362	1222.448	1029.705	364.377	145.313				ACRE FEET
INS				.130	2.113	7.393	6.228	2.203	.878				INCHES
FLOW													
MAX				2.891	17.883	64.608	54.578	18.339	7.204				MAXIMUM
MIN				.000	3.361	18.012	18.790	6.533	.000				MINIMUM

TOTAL SEASONAL RUNOFF 3132.820 ACRE FEET, 18.949 INCHES
SEASONAL PEAK DAILY FLOW 64.608 ACRE FEET, 32.573 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1948

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					3.692	45.541	20.801	7.866	3.948				1
2					3.334	52.466	21.809	7.561	3.721				2
3					3.184	57.950	21.172	7.243	3.496				3
4					3.205	55.184	20.682	7.604	3.381				4
5					3.218	52.872	22.196	7.636	3.416				5
6					3.479	52.254	20.897	8.290	3.733				6
7					4.201	51.706	19.630	7.460	3.875				7
8					4.811	50.188	18.602	6.904	3.807				8
9					4.721	49.511	17.281	6.466	3.535				9
10					3.786	49.118	18.298	6.345	3.360				10
11					3.419	49.251	16.872	6.239	3.311				11
12					3.323	49.009	15.941	6.102	3.309				12
13					3.719	46.927	15.364	6.091	3.268				13
14					5.200	43.817	14.880	6.097	3.263				14
15					6.655	39.352	14.275	5.953	3.213				15
16					8.746	36.202	13.887	5.829	3.201				16
17					12.751	33.596	13.269	5.187	3.197				17
18					14.733	31.988	13.000	4.877	3.145				18
19					19.443	32.635	12.876	4.783	3.215				19
20					24.171	30.027	12.983	4.406	3.155				20
21					28.735	28.063	14.265	4.258	3.120				21
22				2.134	33.314	26.912	12.850	4.299	3.091				22
23				1.286	33.471	26.321	11.333	4.571	1.830				23
24				2.083	33.834	24.460	10.829	4.743					24
25				2.083	35.499	23.482	10.603	5.164					25
26				2.110	32.072	23.086	10.001	6.115					26
27				2.550	33.523	22.724	9.654	5.160					27
28				3.198	37.086	21.234	9.990	4.759					28
29				3.796	34.895	20.092	9.416	4.836					29
30				4.042	39.041	20.591	8.317	4.613					30
31					46.048		7.832	4.131					31
TOTAL													
A-F				23.286	527.325	1146.574	459.820	181.604	76.599				ACRE FEET
INS				.140	3.189	6.934	2.781	1.098	.463				INCHES
FLOW													
MAX				4.042	46.048	57.950	22.196	8.290	3.948				MAXIMUM
MIN				.000	3.184	20.092	7.832	4.131	.000				MINIMUM

TOTAL SEASONAL RUNOFF 2415.212 ACRE FEET, 14.608 INCHES
SEASONAL PEAK DAILY FLOW 57.951 ACRE FEET, 29.216 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD

EAST ST. LOUIS CREEK 1984 ACRES

1949

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					3.100	17.768	38.385	12.794	5.958	4.900			1
2					3.175	16.411	37.739	12.279	5.816	5.079			2
3					4.117	16.385	41.948	13.068	6.467	4.850			3
4					4.528	19.175	41.537	12.462	6.350	4.689			4
5					4.070	21.986	42.573	11.904	5.374	4.538			5
6					3.436	21.944	41.682	11.485	5.285	4.477			6
7					3.444	21.366	43.013	10.940	5.414	4.473			7
8					3.451	22.391	40.053	11.276	5.347	4.474			8
9					3.745	26.849	39.053	11.943	5.305	4.737			9
10					4.064	27.285	37.536	10.972	5.353	4.607			10
11					4.292	33.796	35.204	10.491	5.551	4.788			11
12					4.957	44.684	30.758	10.050	5.359	4.988			12
13					4.695	51.357	27.752	9.585	5.202	4.990			13
14					4.980	51.385	26.873	9.133	5.128	4.859			14
15					7.485	53.200	25.488	8.737	4.891	4.721			15
16					7.526	66.845	24.451	8.414	4.819	4.632			16
17					6.251	76.476	23.959	8.379	4.808	4.853			17
18					5.816	69.528	23.679	8.033	4.781	4.922			18
19					6.244	66.918	23.249	7.643	4.688	3.055			19
20				2.029	6.187	65.345	22.412	7.132	4.396				20
21				1.664	5.626	61.589	21.071	6.805	4.268				21
22				1.664	5.410	59.739	19.423	6.786	4.221				22
23				1.664	5.337	55.707	19.106	6.831	4.416				23
24				2.088	6.074	51.478	18.496	6.673	4.421				24
25				2.751	9.279	48.778	17.791	6.574	4.408				25
26				2.586	13.108	47.443	16.701	6.135	4.487				26
27				2.870	14.912	47.947	15.883	6.028	4.484				27
28				3.060	15.883	44.148	15.319	5.893	4.584				28
29				3.536	19.113	41.195	14.591	5.935	4.688				29
30				3.360	20.729	38.979	14.023	6.027	5.096				30
31					19.706		13.366	6.133					31
TOTAL													
A-F				27.276	230.751	1288.109	853.127	276.555	151.379	88.640			ACRE FEET
INS				.164	1.395	7.790	5.160	1.672	.915	.536			INCHES
FLOW													
MAX				3.536	20.729	76.476	43.013	13.068	6.467	5.079			MAXIMUM
MIN				.000	3.100	16.385	13.366	5.893	4.221	.000			MINIMUM

TOTAL SEASONAL RUNOFF 2915.841 ACRE FEET, 17.636 INCHES
SEASONAL PEAK DAILY FLOW 76.476 ACRE FEET, 38.556 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD

EAST ST. LOUIS CREEK 1984 ACRES

1950

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					3.119	21.120	29.608	7.824	3.970	3.853	3.166		1
2					3.624	25.536	28.127	7.604	3.944	3.741	3.166		2
3					4.770	22.150	26.780	8.499	3.934	3.815	4.341		3
4					4.699	18.982	25.658	7.795	3.664	3.926	3.879		4
5					3.924	22.832	24.339	7.525	3.560	3.938	4.563		5
6					3.481	33.584	22.919	7.384	4.080	3.902	3.182		6
7					3.003	39.970	22.324	7.147	3.871	3.757	3.109		7
8					3.172	36.099	21.526	6.845	3.651	3.764	1.977		8
9					3.096	35.555	20.534	6.508	3.829	3.823			9
10					3.087	44.237	19.861	6.216	4.007	3.825			10
11					3.589	55.721	19.641	6.343	4.110	3.770			11
12					4.040	56.800	18.293	6.076	4.727	3.695			12
13					4.211	59.969	17.379	5.790	4.638	3.678			13
14					4.931	62.173	16.244	5.482	4.459	3.699			14
15					5.140	62.318	15.288	5.307	4.336	3.741			15
16					5.636	76.054	14.604	5.082	4.094	3.704			16
17				1.466	7.674	76.517	14.224	4.913	3.908	3.440			17
18				2.567	7.414	64.919	14.255	4.702	4.025	3.419			18
19				2.504	7.243	56.912	13.802	4.573	5.362	3.433			19
20				2.510	8.497	50.733	13.109	4.695	5.189	3.422			20
21				2.810	10.542	46.850	12.450	4.638	4.002	3.427			21
22				3.536	13.300	44.051	11.771	4.793	3.784	3.331			22
23				3.491	15.061	42.786	11.254	4.858	3.689	3.295			23
24				3.190	15.189	41.419	10.915	5.000	3.659	3.360			24
25				2.769	12.842	39.051	10.338	5.837	3.571	3.329			25
26				2.857	10.400	36.866	10.120	6.336	3.820	3.306			26
27				3.150	9.334	35.859	9.841	5.667	3.907	3.485			27
28				3.192	9.120	34.633	9.382	5.169	4.101	3.369			28
29				3.197	9.470	33.456	9.230	4.902	4.105	3.253			29
30				3.166	11.919	31.596	9.057	4.743	3.825	3.309			30
31					15.868		8.387	4.267		3.313			31
TOTAL													
A-F				40.410	227.408	1308.764	511.273	182.536	121.840	111.135	27.386		ACRE FEET
INS				.244	1.375	7.915	3.092	1.104	.736	.672	.165		INCHES
FLOW													
MAX				3.536	15.868	76.517	29.608	8.499	5.362	3.938	4.563		MAXIMUM
MIN				.000	3.003	18.982	8.387	4.267	3.560	3.253	.000		MINIMUM

TOTAL SEASONAL RUNOFF 2530.755 ACRE FEET, 15.307 INCHES
SEASONAL PEAK DAILY FLOW 76.517 ACRE FEET, 38.577 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1951

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1				2.418	2.418	29.825	53.046						1
2				2.418	2.427	24.165	51.967						2
3				2.418	2.521	21.600	51.077						3
4				2.418	2.773	19.074	51.652						4
5				2.418	3.255	18.025	47.878						5
6				2.418	3.254	18.071	46.337						6
7				2.418	3.417	19.118	46.220						7
8				2.418	3.218	19.739	44.425						8
9				2.418	2.833	19.671	41.097						9
10				2.418	2.703	19.509	38.516						10
11				2.418	2.948	18.785	36.787						11
12				2.418	3.638	18.800	35.162						12
13				2.418	3.647	20.808	32.831						13
14				2.418	3.148	22.961	31.691						14
15				2.418	3.516	26.463	29.930						15
16				2.418	4.668	36.012	28.694						16
17				2.418	4.753	50.424	28.098						17
18				2.418	4.704	67.729	27.277						18
19				2.418	5.720	66.405	25.844						19
20				2.418	7.178	69.197	27.230						20
21				2.418	7.442	84.221	27.129						21
22				2.418	7.662	68.872	25.039						22
23				2.418	9.380	60.475	22.917						23
24				2.418	9.630	57.908	20.884						24
25				2.418	10.041	61.128	19.275						25
26				2.418	11.504	61.973	18.555						26
27				2.418	14.544	61.343	18.225						27
28				2.418	19.917	59.263	17.802						28
29				2.418	22.103	56.537	.983						29
30				2.418	27.935	54.414							30
31			.844		33.328								31
TOTAL													
A-F			.844	72.541	246.237	1232.530	946.582						ACRE FEET
INS			.005	.438	1.489	7.454	5.725						INCHES
FLOW													
MAX			.844	2.418	33.328	84.221	53.046						MAXIMUM
MIN			.000	2.418	2.418	18.025	.000						MINIMUM

TOTAL SEASONAL RUNOFF 2498.736 ACRE FEET, 15.113 INCHES
SEASONAL PEAK DAILY FLOW 84.222 ACRE FEET, 42.461 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1952

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					3.912	21.791	39.201	13.188	8.082	5.326			1
2					4.651	24.838	37.195	12.517	7.480	5.326			2
3					5.855	35.304	35.014	11.806	7.205	5.289			3
4					7.200	41.158	32.677	11.842	7.247	5.141			4
5					8.509	44.918	30.290	11.326	7.001	5.141			5
6					8.435	62.279	30.057	10.546	7.042				6
7					8.090	76.560	27.657	12.179	7.001				7
8					8.657	80.398	25.423	11.091	6.853				8
9					7.962	85.801	24.428	10.174	6.598				9
10					6.659	98.942	23.478	13.237	6.479				10
11					6.262	98.834	22.240	12.386	6.439				11
12					6.700	97.340	21.172	10.524	6.518				12
13					8.904	95.279	20.237	10.589	6.839				13
14					11.672	92.549	19.306	10.337	6.360				14
15					12.336	96.086	18.410	9.605	6.164				15
16					11.885	82.442	17.795	9.022	6.368				16
17					10.245	70.698	17.215	8.801	6.242				17
18					9.244	63.852	17.100	8.475	6.008				18
19					8.944	65.568	16.534	10.292	5.854				19
20					8.647	65.741	15.887	9.491	5.778				20
21					8.669	60.657	15.576	10.412	5.740				21
22					8.171	57.176	14.909	9.560	5.664				22
23				2.995	7.915	52.649	14.310	9.182	5.588				23
24				3.119	7.892	50.452	15.287	8.911	5.626				24
25				3.422	8.468	49.197	17.233	8.188	5.626				25
26				3.901	9.416	46.763	16.397	8.444	5.588				26
27				4.522	10.243	45.199	15.902	8.495	5.513				27
28				4.852	12.303	42.090	15.679	8.779	5.513				28
29				4.332	14.911	41.170	14.544	8.844	5.550				29
30				3.945	16.890	39.773	13.592	8.068	5.450				30
31					18.758		14.035	7.625					31
TOTAL													
A-F				31.090	288.418	1885.515	658.793	313.952	189.428	26.224			ACRE FEET
INS				.188	1.744	11.404	3.984	1.898	1.145	.158			INCHES
FLOW													
MAX				4.852	18.758	98.942	39.201	13.237	8.082	5.326			MAXIMUM
MIN				.000	3.912	21.791	13.592	7.625	5.450	.000			MINIMUM

TOTAL SEASONAL RUNOFF 3393.423 ACRE FEET, 20.525 INCHES
SEASONAL PEAK DAILY FLOW 98.943 ACRE FEET, 49.883 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK   1984 ACRES

1953

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					2.889	27.389	27.162	15.792	6.603				1
2					2.858	32.167	25.830	15.065	6.479				2
3					2.858	31.977	23.905	13.739	6.360				3
4					2.900	30.353	22.360	12.564	6.242				4
5					2.919	27.155	21.024	12.024	6.125				5
6					3.058	27.075	19.116	11.444	6.008				6
7					3.228	26.737	18.101	10.903	5.931				7
8					3.276	29.325	17.463	10.591	5.816				8
9					3.197	39.537	18.909	10.266	5.702				9
10					3.134	48.603	19.155	10.297	5.588				10
11					3.134	53.621	23.055	9.944	5.475				11
12					3.103	63.029	17.951	9.535	5.400				12
13					3.072	71.814	16.488	9.087	5.289				13
14					3.041	63.397	15.699	9.311	5.178				14
15					3.011	58.230	14.907	8.955	5.132				15
16					2.980	54.930	15.386	8.691	5.104				16
17					2.949	53.779	14.716	8.404	4.922				17
18					2.949	55.677	13.162	8.672	4.958				18
19					2.919	62.651	12.170	8.000	4.834				19
20					2.889	55.199	11.787	7.704	4.850				20
21					3.385	47.762	11.540	7.558	4.742				21
22					4.476	43.541	11.588	8.285	4.707				22
23					5.174	40.229	11.062	7.704	4.742				23
24				2.591	7.388	37.514	10.701	7.288	4.778				24
25				2.577	9.161	34.562	10.498	7.083	4.814				25
26				2.776	10.603	32.030	11.020	7.001	4.760				26
27				3.070	16.616	30.780	12.404	7.288	4.635				27
28				3.197	24.318	30.223	12.100	7.351	4.635				28
29				2.919	22.773	27.611	14.530	7.205	4.529				29
30				2.919	18.979	27.461	12.903	7.123					30
31					23.196		13.257	6.758					31
TOTAL													
A-F				20.051	206.450	1264.374	499.964	291.651	154.354				ACRE FEET
INS				.121	1.248	7.647	3.023	1.764	.933				INCHES
FLOW													
MAX				3.197	24.318	71.814	27.162	15.792	6.603				MAXIMUM
MIN				.000	2.858	26.737	10.498	6.758	.000				MINIMUM

TOTAL SEASONAL RUNOFF   2436.846 ACRE FEET,   14.739 INCHES
SEASONAL PEAK DAILY FLOW   71.814 ACRE FEET,   36.206 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK   1984 ACRES

1954

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					3.499	11.665	9.672	5.068	3.678	4.088			1
2					3.376	10.669	9.490	4.792	3.777	4.080			2
3					3.944	11.377	8.999	4.565	4.089	4.080			3
4					4.121	12.088	8.603	4.529	4.565	4.080			4
5					4.607	13.184	8.366	6.291	4.216	4.182			5
6					5.105	12.773	8.128	6.062	4.027	4.148			6
7					5.329	11.539	7.915	4.995	3.928	4.148			7
8					6.125	10.600	7.958	4.600	4.514	4.135			8
9					6.877	10.519	7.704	4.747	4.285	4.285			9
10					6.887	10.634	7.495	4.778	3.899	4.494			10
11					6.669	10.617	7.247	4.995	3.811	4.445			11
12					7.540	10.945	7.019	6.125	3.944	4.355			12
13					7.427	11.441	7.518	5.475	3.877	4.407			13
14				3.228	8.845	11.786	7.815	5.068	3.749	4.269			14
15				2.980	9.645	11.124	7.453	5.068	3.678	4.925			15
16				2.965	10.328	11.470	7.646	5.141	3.646	4.529			16
17				3.408	12.245	12.920	8.456	4.869	3.580	4.636			17
18				3.493	12.989	14.089	7.083	4.494	3.577				18
19				3.475	15.419	14.562	6.852	4.529	3.580				19
20				3.323	17.552	14.130	6.598	4.565	3.510				20
21				3.260	17.939	13.482	6.518	4.886	3.613				21
22				3.460	16.944	13.364	6.758	4.635	3.548				22
23				3.865	15.328	13.263	6.479	4.460	4.854				23
24				4.334	13.935	13.263	6.047	4.182	5.781				24
25				4.015	14.179	13.045	6.314	4.216	4.216				25
26				3.642	14.017	12.465	6.264	4.114	4.182				26
27				3.882	12.716	12.962	5.778	4.046	5.420				27
28				4.503	11.912	11.369	5.513	3.945	4.850				28
29				4.498	11.347	10.359	5.215	3.877	4.148				29
30				3.754	12.246	9.807	5.438	3.750	4.389				30
31					12.317		5.178	3.678					31
TOTAL													
A-F				62.093	311.424	361.525	223.533	146.562	122.946	73.292			ACRE FEET
INS				.375	1.883	2.186	1.352	.886	.743	.443			INCHES
FLOW													
MAX				4.503	17.939	14.562	9.672	6.291	5.781	4.925			MAXIMUM
MIN				.000	3.376	9.807	5.178	3.678	3.510	.000			MINIMUM

TOTAL SEASONAL RUNOFF   1301.379 ACRE FEET,   7.871 INCHES
SEASONAL PEAK DAILY FLOW   17.940 ACRE FEET,   9.045 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1955

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					5.254	17.268	21.259	11.318	6.482	4.389			1
2					5.404	17.261	20.571	10.732	6.087	4.424			2
3					4.865	15.861	19.688	11.072	5.970	4.398			3
4					4.541	14.776	18.889	11.417	5.854	4.490			4
5					5.290	14.000	18.102	10.779	5.740	4.922			5
6					6.399	14.756	17.380	11.291	5.664				6
7					8.086	16.996	16.940	11.511	5.626				7
8					7.840	22.681	16.235	11.067	5.513				8
9					5.734	19.861	15.700	9.580	5.289				9
10					5.734	17.435	15.275	8.778	5.141				10
11					6.307	19.343	16.606	8.472	5.141				11
12					7.263	22.706	14.983	8.214	4.995				12
13					8.639	24.969	13.974	8.410	4.916				13
14					11.652	26.715	13.012	9.720	4.995				14
15					13.603	24.520	12.268	8.742	4.995				15
16					10.862	25.141	11.903	8.262	4.958				16
17					10.171	25.147	11.015	8.603	4.894				17
18					8.291	24.520	10.392	11.809	4.886				18
19					7.495	24.520	9.898	9.697	4.850				19
20					9.471	24.569	9.445	8.761	5.146				20
21					12.911	25.328	9.310	7.939	4.886				21
22					14.265	26.398	8.911	7.615	4.707				22
23					14.856	27.226	14.281	7.453	4.565				23
24					16.471	26.406	11.926	7.412	4.621				24
25					16.060	25.203	11.799	7.912	4.671				25
26					14.779	24.335	14.856	8.599	4.603				26
27					12.420	23.538	14.731	10.087	4.600				27
28					11.367	22.887	14.589	9.168	4.565				28
29					12.455	22.569	13.470	7.788	4.601				29
30				4.778	12.794	21.970	12.121	7.413	4.389				30
31					14.717		11.540	6.883					31
TOTAL													
A-F				4.778	306.011	658.921	441.085	286.522	153.361	22.626			ACRE FEET
INS				.028	1.850	3.985	2.667	1.732	.927	.136			INCHES
FLOW													
MAX				4.778	16.471	27.226	21.259	11.809	6.482	4.922			MAXIMUM
MIN				.000	4.541	14.000	8.911	6.883	4.389	.000			MINIMUM

TOTAL SEASONAL RUNOFF 1873.308 ACRE FEET, 11.330 INCHES
SEASONAL PEAK DAILY FLOW 27.226 ACRE FEET, 13.726 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1956

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1						55.856	21.318	9.196	5.252	3.679			1
2						60.470	19.654	8.822	5.252	3.678			2
3					3.748	57.787	19.019	6.314	5.141	3.711			3
4					4.379	55.299	17.989	5.829	5.141	3.744			4
5					5.061	55.389	17.070	5.236	5.141	3.744			5
6					6.179	54.452	16.451	5.252	5.141	3.744			6
7					7.776	51.897	15.528	4.885	5.104	3.777			7
8					8.976	50.967	14.896	4.762	5.104	3.800			8
9					8.527	50.101	14.691	4.303	5.141	3.744			9
10					7.875	49.471	13.690	4.204	5.013	3.711			10
11					8.221	49.547	13.674	4.182	5.031	3.811			11
12					9.933	52.937	13.486	4.320	5.104	3.811			12
13					9.466	46.239	14.038	4.459	4.995				13
14					7.788	45.242	13.234	4.320	4.850				14
15					7.267	43.732	12.181	5.885	4.742				15
16					7.965	41.058	10.602	5.741	4.635				16
17					11.203	38.516	9.572	4.958	4.494				17
18					15.046	38.014	9.190	4.882	4.389				18
19					17.604	35.643	8.661	11.337	4.285				19
20					20.305	33.597	8.147	9.292	4.182				20
21					24.149	31.157	7.547	7.042	4.080				21
22					30.846	29.038	10.140	6.879	3.978				22
23					38.446	27.547	8.089	6.718	3.877				23
24					36.503	26.145	6.844	6.558	3.777				24
25					39.100	25.736	6.357	6.479	3.678				25
26					41.279	24.644	6.207	6.281	3.678				26
27					39.236	23.416	6.711	5.952	3.580				27
28					39.821	22.569	6.047	5.740	3.678				28
29					43.381	21.851	23.824	5.550	3.646				29
30					46.789	22.475	13.076	5.513	3.646				30
31					52.453		11.851	5.442					31
TOTAL													
A-F					599.336	1220.804	389.801	186.347	135.773	44.961			ACRE FEET
INS					3.625	7.383	2.357	1.127	.821	.271			INCHES
FLOW													
MAX					52.453	60.470	23.824	11.337	5.252	3.811			MAXIMUM
MIN					.000	21.851	6.047	4.182	3.580	.000			MINIMUM

TOTAL SEASONAL RUNOFF 2577.024 ACRE FEET, 15.587 INCHES
SEASONAL PEAK DAILY FLOW 60.470 ACRE FEET, 30.487 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1957

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1						6.006	106.951	23.294	9.853	5.513			I
2						8.477	97.001	21.614	9.355	5.475			2
3						11.581	102.429	19.002	8.910	5.289			3
4						14.315	97.531	18.437	8.560				4
5						18.923	83.321	19.380	8.257				5
6						24.549	75.802	20.107	8.257				6
7						31.080	72.471	17.490	8.086				7
8						34.567	63.954	16.559	7.788				8
9						35.965	57.400	16.127	7.426				9
10						37.612	54.794	15.593	7.123				10
11						35.868	51.694	15.169	7.164				11
12						37.962	49.548	14.907	7.029				12
13						39.785	46.964	14.283	7.628				13
14						32.263	45.236	13.719	8.326				14
15						34.434	41.868	16.702	8.845				15
16						31.962	40.545	15.064	8.205				16
17						27.566	41.103	13.923	7.620				17
18						32.986	48.166	13.364	6.960				18
19						39.045	49.851	13.364	6.839				19
20						42.052	37.657	13.062	7.288				20
21						40.723	35.188	15.408	7.042				21
22						35.018	33.459	14.128	6.541				22
23						36.538	33.459	13.062	6.638				23
24					2.709	41.900	30.888	12.515	6.399				24
25					2.701	52.801	28.516	12.416	6.164				25
26					2.791	63.773	28.386	12.416	6.047				26
27					2.927	71.351	27.804	11.878	5.854				27
28					3.113	80.823	26.019	11.205	5.854				28
29					3.736	105.120	26.145	11.492	5.702				29
30					4.737	111.015	25.516	10.968	5.588				30
31					5.499		23.966	10.452					31
TOTAL													
A-F					28.216	1216.076	1583.648	467.114	221.365	16.277			ACRE FEET
INS					.170	7.355	9.578	2.825	1.338	.098			INCHES
FLOW													
MAX					5.499	111.015	106.951	23.294	9.853	5.513			MAXIMUM
MIN					.000	6.006	23.966	10.452	5.588	.000			MINIMUM

TOTAL SEASONAL RUNOFF 3532.699 ACRE FEET, 21.367 INCHES
SEASONAL PEAK DAILY FLOW 111.016 ACRE FEET, 55.970 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1958

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1						50.684	15.806	6.120	4.046	3.548			I
2						51.617	15.593	5.961	3.911	3.515			2
3						52.106	14.750	5.855	3.991	3.399			3
4						50.635	14.257	5.882	3.944	3.387			4
5						52.127	13.617	5.836	3.811	3.387			5
6						53.486	12.713	5.570	3.744	3.419			6
7						53.437	12.138	5.394	3.761	3.371			7
8					4.110	50.717	11.338	5.181	3.740	3.355			8
9					3.613	47.396	10.593	5.104	3.819	3.260			9
10					3.800	43.075	10.137	5.651	3.811	3.291			10
11					5.416	39.548	9.793	5.404	3.777	3.323			11
12					7.883	35.713	9.519	5.129	3.777	3.291			12
13					7.830	33.169	9.158	4.995	3.744	3.291			13
14					6.914	32.075	8.904	4.958	3.744				14
15					5.908	29.613	8.686	4.958	3.744				15
16					5.874	28.527	8.516	4.779	3.711				16
17					6.443	27.067	8.430	4.778	3.711				17
18					8.533	27.219	8.902	6.940	3.678				18
19					11.393	25.956	8.307	5.748	3.678				19
20					15.338	24.520	7.964	5.031	3.678				20
21					20.081	25.444	7.831	4.778	3.646				21
22					22.951	22.870	7.711	5.319	3.646				22
23					31.367	21.941	7.254	5.463	3.646				23
24					37.190	21.495	7.105	5.113	3.613				24
25					40.162	22.268	7.100	4.707	3.586				25
26					41.955	20.497	6.996	4.523	3.483				26
27					45.039	18.551	8.638	4.494	3.483				27
28					50.177	17.767	6.957	4.454	3.451				28
29					54.365	17.214	6.301	4.494	3.411				29
30					54.179	16.528	6.631	4.260	3.515				30
31					52.356		6.399	4.148					31
TOTAL													
A-F					542.888	1013.279	298.060	161.044	111.317	43.843			ACRE FEET
INS					3.283	6.128	1.802	.974	.673	.265			INCHES
FLOW													
MAX					54.365	53.486	15.806	6.940	4.046	3.548			MAXIMUM
MIN					.000	16.528	6.301	4.148	3.411	.000			MINIMUM

TOTAL SEASONAL RUNOFF 2170.434 ACRE FEET, 13.128 INCHES
SEASONAL PEAK DAILY FLOW 54.365 ACRE FEET, 27.409 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1959

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1						15.766	23.843	10.732	4.671				1
2						16.464	22.637	10.014	4.600				2
3						16.559	22.269	10.190	4.459				3
4						18.132	21.614	9.990	4.320				4
5						21.241	21.141	8.822	4.182				5
6						26.003	20.381	8.790	4.046				6
7						31.152	19.918	8.257	3.944				7
8						34.013	19.401	7.662	3.811				8
9						37.235	18.269	7.412	3.711				9
10						39.590	17.656	7.123	3.678				10
11					3.275	39.771	16.995	7.001	3.646				11
12					4.435	39.347	15.918	7.123	3.515				12
13					5.273	39.121	15.699	6.920	3.419				13
14					6.847	39.307	15.117	6.758	3.516				14
15					8.210	40.133	14.762	6.678	3.734				15
16					8.355	42.670	15.171	6.439	5.366				16
17					8.296	41.196	13.806	6.242	4.600				17
18					8.826	39.022	13.162	6.086	4.343				18
19					8.563	39.893	12.614	6.125	3.911				19
20					7.704	43.817	12.024	6.125	3.877				20
21					7.001	41.759	11.540	6.086	3.711				21
22					6.668	38.049	10.826	5.778	3.613				22
23					7.092	34.841	10.405	5.513	3.811				23
24					8.773	33.859	10.098	6.465	4.012				24
25					8.818	32.572	9.960	6.518	4.148				25
26					8.075	30.215	10.513	6.008	4.182				26
27					8.814	29.248	9.724	5.588	4.389				27
28					11.049	30.773	9.221	5.252	4.355				28
29					13.331	27.162	9.760	5.104	4.285				29
30					14.424	25.384	10.609	4.958	4.074				30
31					14.979		12.637	4.814					31
TOTAL													
A-F					178.818	984.308	467.703	216.589	121.944				ACRE FEET
INS					1.081	5.953	2.828	1.310	.737				INCHES
FLOW													
MAX					14.979	43.817	23.843	10.732	5.366				MAXIMUM
MIN					.000	15.766	9.221	4.814	3.419				MINIMUM

TOTAL SEASONAL RUNOFF 1969.366 ACRE FEET, 11.911 INCHES
SEASONAL PEAK DAILY FLOW 43.818 ACRE FEET, 22.091 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1960

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1						22.854	25.778	11.011	5.215	3.678			1
2						26.240	25.016	9.671	5.178	3.646			2
3						30.808	25.016	9.087	5.141	3.613			3
4						35.453	23.843	8.735	5.068	3.580			4
5						39.096	22.629	8.528	5.031	3.548			5
6						35.165	21.792	8.257	4.958	3.646			6
7						33.678	21.053	7.958	4.922	3.548			7
8						34.631	19.918	7.704	4.850	3.613			8
9						34.867	18.945	7.495	4.814	3.697			9
10					3.527	36.000	19.358	7.329	4.742	3.744			10
11					4.706	35.764	19.059	7.083	4.707	3.613			11
12					6.694	34.227	17.989	6.839	4.635	3.515			12
13					8.465	35.175	17.269	6.715	4.600	3.520			13
14					8.960	36.675	16.451	6.718	4.529	3.744			14
15					8.989	40.320	15.954	6.439	4.494	3.419			15
16					9.088	47.918	15.169	6.439	4.459	3.679			16
17					9.884	52.325	14.802	6.518	4.389	3.678			17
18					9.854	51.823	14.283	6.203	4.355	3.580			18
19					8.801	51.514	13.719	6.044	4.285	3.646			19
20					8.473	50.418	13.213	5.893	4.251	3.483			20
21					9.746	46.149	12.812	5.664	4.182	3.435			21
22					10.828	42.439	12.632	5.588	4.148	3.451			22
23					13.491	38.157	12.515	5.854	4.080	3.419			23
24					13.775	34.870	12.170	5.513	4.046	3.419			24
25					12.962	32.844	11.492	6.125	3.978	3.291			25
26					14.159	31.693	10.968	5.438	3.911	3.198			26
27					16.722	30.356	10.405	5.400	3.877				27
28					16.506	29.038	10.711	5.363	3.811				28
29					17.804	28.062	10.656	5.326	3.777				29
30					19.459	27.098	10.128	5.289	3.711				30
31					20.620		11.682	5.252					31
TOTAL													
A-F					253.522	1105.671	507.443	211.489	134.159	92.416			ACRE FEET
INS					1.533	6.687	3.069	1.279	.811	.558			INCHES
FLOW													
MAX					20.620	52.325	25.778	11.011	5.215	3.744			MAXIMUM
MIN					.000	22.854	10.128	5.252	3.711	.000			MINIMUM

TOTAL SEASONAL RUNOFF 2304.705 ACRE FEET, 13.940 INCHES
SEASONAL PEAK DAILY FLOW 52.325 ACRE FEET, 26.380 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1961

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1						24.229	19.719	8.090	5.702				1
2						23.463	18.381	7.873	5.626				2
3						20.536	17.324	7.370	5.893				3
4						19.194	17.662	7.001	5.970				4
5						19.114	16.611	6.718	6.770				5
6						19.773	15.169	6.583	7.217				6
7						23.634	15.169	6.524	7.873				7
8						28.441	14.646	7.106	8.534				8
9						29.770	14.231	6.540	8.962				9
10						30.381	13.465	6.320	8.738				10
11						30.945	13.062	6.047	7.746				11
12						31.592	12.443	6.793	7.329				12
13						30.727	11.636	6.558	7.042				13
14						28.570	11.348	6.164	6.879				14
15						26.985	11.205	5.854	6.718				15
16						27.627	10.325	6.620	6.718				16
17						28.285	9.762	7.468	6.638				17
18						27.099	9.310	6.360	6.963				18
19					5.800	26.934	8.981	5.816	7.288				19
20					6.770	28.021	10.652	5.550	7.412				20
21					7.267	27.039	11.379	5.550	7.559				21
22					8.086	26.107	9.625	5.438	7.453				22
23					8.284	24.684	8.485	5.212	7.288				23
24					8.276	23.599	8.214	6.048	6.809				24
25					8.766	22.569	8.257	6.008	7.796				25
26					10.151	21.970	8.177	5.702	7.070				26
27					12.331	21.068	7.662	5.400	6.880				27
28					13.030	20.614	8.371	5.178	7.083				28
29					16.376	19.918	7.704	4.995	7.453				29
30					19.382	20.123	7.736	6.149	6.920				30
31					20.822		8.300	6.320					31
TOTAL													
A-F					145.346	753.028	365.026	195.371	214.343				ACRE FEET
INS					.879	4.554	2.207	1.181	1.296				INCHES
FLOW													
MAX					20.822	31.592	19.719	8.090	8.962				MAXIMUM
MIN					.000	19.114	7.662	4.995	5.626				MINIMUM

TOTAL SEASONAL RUNOFF 1673.116 ACRE FEET, 10.120 INCHES
SEASONAL PEAK DAILY FLOW 31.592 ACRE FEET, 15.928 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1962

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					4.958	20.091	61.414	14.517	6.758				1
2					4.922	22.210	52.199	13.823	6.608				2
3					4.958	25.273	49.668	13.841	6.439				3
4					5.400	29.699	46.838	13.531	6.320				4
5					6.028	31.396	44.179	12.534					5
6					6.926	33.524	42.174	11.968					6
7					8.885	35.027	40.649	11.412					7
8					10.743	30.688	39.236	10.992					8
9					13.755	29.384	37.942	10.697					9
10					16.300	30.986	35.224	10.348					10
11					19.489	33.865	32.664	10.307					11
12					23.721	40.612	35.367	10.036					12
13					24.832	46.501	32.435	9.716					13
14					22.857	48.349	29.563	9.310					14
15					21.851	47.994	27.226	9.078					15
16					21.732	44.179	25.016	8.869					16
17					20.439	40.838	24.229	8.757					17
18					19.059	40.399	23.173	8.720					18
19				4.001	21.614	43.381	22.149	10.761					19
20				4.565	20.091	49.376	21.459	9.332					20
21				4.529	19.173	54.633	20.776	9.356					21
22				3.923	17.809	57.007	19.925	8.688					22
23				4.046	17.490	55.057	19.885	8.584					23
24				4.837	18.832	54.349	19.549	8.683					24
25				5.457	19.860	54.329	19.093	8.128					25
26				5.588	20.178	54.803	18.663	7.831					26
27				4.922	20.033	54.124	17.643	7.661					27
28				5.068	18.832	53.266	16.668	7.370					28
29				5.400	18.388	55.848	15.913	7.123					29
30				4.995	18.550	60.038	15.337	7.040					30
31					19.458		15.077	6.879					31
TOTAL													
A-F				57.336	507.180	1277.243	921.349	305.907	26.127				ACRE FEET
INS				.346	3.067	7.725	5.572	1.850	.158				INCHES
FLOW													
MAX				5.588	24.832	60.038	61.414	14.517	6.758				MAXIMUM
MIN				.000	4.922	20.091	15.077	6.879	.000				MINIMUM

TOTAL SEASONAL RUNOFF 3095.146 ACRE FEET, 18.721 INCHES
SEASONAL PEAK DAILY FLOW 61.414 ACRE FEET, 30.963 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1963

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1						14.066	8.490						1
2						15.633	8.247						2
3						15.500	8.161						3
4					3.308	14.508	7.868						4
5					3.739	14.204	7.594						5
6					4.748	13.788	7.352						6
7					5.702	13.799	6.982						7
8					6.425	13.484	6.951						8
9					8.325	14.360	7.780						9
10					8.996	13.044	7.428						10
11					9.838	11.796	6.879						11
12					8.952	11.626	6.605						12
13					9.285	12.604	6.439						13
14					9.825	13.086	6.281						14
15					12.490	14.612	6.198						15
16					12.083	18.213	6.047						16
17					12.301	14.457	5.931						17
18					13.944	14.894	5.740						18
19					12.727	13.783	5.491						19
20					12.966	13.117	5.326						20
21					13.156	12.590	5.293						21
22					12.679	12.126	7.059						22
23					13.235	11.884	6.667						23
24					14.493	11.311	5.993						24
25					13.995	10.989							25
26					13.291	10.430							26
27					13.515	10.049							27
28					14.104	9.608							28
29					14.298	9.266							29
30					14.562	8.647							30
31					14.068								31
TOTAL													
A-F					307.068	387.488	162.813						ACRE FEET
INS					1.857	2.343	.984						INCHES
FLOW													
MAX					14.562	18.213	8.490						MAXIMUM
MIN					.000	8.647	.000						MINIMUM

TOTAL SEASONAL RUNOFF 857.371 ACRE FEET, 5.186 INCHES
SEASONAL PEAK DAILY FLOW 18.214 ACRE FEET, 9.183 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1964

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1						15.527	18.646	8.871	3.663	3.871			1
2						15.562	18.234	8.409	3.509	3.782			2
3						15.667	18.030	8.304	3.583	3.683			3
4						15.751	17.800	9.188	3.554	3.634			4
5						16.569	17.703	8.162	3.522	3.595			5
6						18.909	17.221	7.444	3.532	3.655			6
7						24.319	16.459	9.329	3.504	3.500			7
8						23.228	15.921	8.698	3.446	3.419			8
9						22.592	15.426	7.429	3.563	3.395			9
10						26.222	15.496	6.919	3.464	3.508			10
11						27.236	14.872	6.485	3.437	3.495			11
12						26.389	14.168	6.363	3.422	3.443			12
13						25.646	13.715	6.241	3.387	3.419			13
14					3.806	23.514	13.369	6.053	3.458				14
15					5.191	24.871	12.778	5.824	3.442				15
16					6.262	26.448	12.459	5.874	3.512				16
17					4.576	26.949	12.073	5.708	3.483				17
18					9.066	25.021	11.653	5.377	3.732				18
19					9.525	23.345	10.953	5.767	4.541				19
20					11.724	22.430	10.473	5.680	4.242				20
21					15.173	21.307	9.908	5.285	4.126				21
22					16.890	20.469	10.017	5.015	4.046				22
23					17.218	19.508	10.161	4.788	3.960				23
24					18.883	19.718	10.967	4.663	3.911				24
25					22.442	20.111	9.394	4.651	3.971				25
26					25.288	20.018	8.915	4.503	4.115				26
27					23.313	19.874	8.508	5.137	4.221				27
28					22.016	19.998	8.217	4.481	4.051				28
29					19.757	19.642	8.143	4.535	3.946				29
30					17.802	19.005	8.803	4.221	3.898				30
31					16.373		9.995	3.912					31
TOTAL													
A-F					265.314	645.861	400.492	193.333	112.256	46.404			ACRE FEET
INS					1.604	3.906	2.422	1.169	.678	.280			INCHES
FLOW													
MAX					25.288	27.236	18.646	9.329	4.541	3.871			MAXIMUM
MIN					.000	15.527	8.143	3.912	3.387	.000			MINIMUM

TOTAL SEASONAL RUNOFF 1663.662 ACRE FEET, 10.062 INCHES
SEASONAL PEAK DAILY FLOW 27.236 ACRE FEET, 13.732 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1965

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					2.404	10.995	40.867	20.208	7.712	5.200			1
2					2.907	11.356	41.046	18.362	7.673	5.533			2
3					2.955	13.299	39.904	18.272	7.825	5.587			3
4					3.175	13.513	37.771	17.173	7.483	5.308			4
5					3.004	12.728	36.206	16.331	7.232	5.083			5
6					2.504	13.304	34.807	15.269	6.997	4.853			6
7					2.276	15.299	33.290	14.624	6.993	4.757			7
8					2.240	19.238	32.391	13.894	6.701	4.609			8
9					2.002	23.574	30.250	13.220	6.341	4.468			9
10					1.830	32.269	29.404	12.716	6.130	4.394			10
11					1.871	34.090	28.435	12.342	6.252	4.286			11
12					2.217	29.464	28.333	11.935	6.146	4.116			12
13					2.534	37.130	26.935	11.538	5.770	4.105			13
14					2.304	42.136	25.057	11.287	5.544	4.067			14
15					2.181	49.566	23.149	11.042	5.491	4.046			15
16					2.402	62.038	24.545	10.510	5.187	4.080			16
17					3.873	75.643	23.990	10.813	5.497	4.080			17
18					4.342	74.988	24.357	12.380	5.560	4.046			18
19					4.748	70.553	24.572	15.472	5.920	4.080			19
20					6.312	66.071	23.128	14.051	5.785	4.106			20
21					8.072	61.821	22.257	11.769	5.279	4.176			21
22				1.627	12.168	57.092	23.453	10.749	5.503	1.819			22
23				1.757	13.990	52.293	26.688	10.386	5.492				23
24				1.666	11.791	51.650	27.046	10.041	5.808				24
25				1.323	9.357	49.358	24.073	9.436	5.815				25
26				1.208	8.130	45.867	22.167	8.951	5.691				26
27				1.231	7.325	42.533	21.994	8.686	5.385				27
28				1.217	6.865	42.865	20.327	8.579	5.347				28
29				1.369	7.321	43.448	18.743	8.684	5.489				29
30				1.822	9.289	41.678	18.858	8.420	5.072				30
31					10.720		24.933	8.037					31
TOTAL													
A-F				13.226	163.125	1195.873	858.991	385.192	183.133	96.807			ACRE FEET
INS				.079	.986	7.233	5.195	2.329	1.107	.585			INCHES
FLOW													
MAX				1.822	13.990	75.643	41.046	20.208	7.825	5.587			MAXIMUM
MIN				.000	1.830	10.995	18.743	8.037	5.072	.000			MINIMUM

TOTAL SEASONAL RUNOFF 2896.349 ACRE FEET, 17.518 INCHES
SEASONAL PEAK DAILY FLOW 75.643 ACRE FEET, 38.136 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1966

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					2.682	18.319	12.468	5.336	3.418	2.595			1
2					3.145	20.084	11.622	5.224	3.357	2.680			2
3					3.633	20.383	10.912	5.734	3.228	2.940			3
4					4.590	19.502	10.214	6.621	3.032	2.952			4
5					5.557	18.124	10.026	5.657	2.810	3.040			5
6					6.316	16.441	9.833	5.373	2.986	3.022			6
7					7.779	15.981	9.231	4.778	3.031	3.018			7
8					7.693	16.572	8.869	4.413	3.106	2.943			8
9					7.511	15.740	8.722	4.555	2.805	2.768			9
10					7.264	16.695	8.775	4.423	2.770	2.589			10
11					5.616	16.697	9.317	4.168	2.986	2.745			11
12					4.793	16.562	8.788	4.809	3.093	1.282			12
13					4.704	15.242	8.568	4.298	3.051				13
14					4.526	15.363	8.059	4.128	2.869				14
15					4.711	16.166	7.643	3.884	3.479				15
16					6.038	16.074	7.444	3.648	3.225				16
17					6.593	15.710	9.029	3.619	3.085				17
18					7.336	15.645	8.756	3.515	2.848				18
19					8.119	15.251	9.146	4.054	2.677				19
20					9.558	15.321	8.311	4.304	2.660				20
21					12.260	14.529	8.794	3.868	2.614				21
22					15.111	14.359	15.446	3.490	2.510				22
23				1.817	13.453	14.108	7.752	3.344	2.498				23
24				1.791	13.782	13.608	7.335	3.276	2.557				24
25				2.009	16.737	13.245	7.114	3.111	2.980				25
26				2.305	15.534	13.165	7.017	3.051	2.629				26
27				2.020	13.901	12.402	7.347	3.026	2.617				27
28				1.802	13.805	12.007	6.464	2.898	2.594				28
29				2.045	15.797	11.858	5.973	2.799	2.519				29
30				2.445	20.295	12.603	5.686	2.884	2.584				30
31					19.807		5.459	3.088					31
TOTAL													
A-F				16.239	288.662	467.772	270.132	127.391	86.631	32.580			ACRE FEET
INS				.098	1.745	2.829	1.633	.770	.523	.197			INCHES
FLOW													
MAX				2.445	20.295	20.383	15.446	6.621	3.479	3.040			MAXIMUM
MIN				.000	2.682	11.858	5.459	2.799	2.498	.000			MINIMUM

TOTAL SEASONAL RUNOFF 1289.410 ACRE FEET, 7.799 INCHES
SEASONAL PEAK DAILY FLOW 20.384 ACRE FEET, 10.277 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1967

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					1.689	18.272	31.550	8.351	4.074	3.139			1
2					1.689	25.494	30.025	8.129	3.963	3.006			2
3					1.740	29.079	28.300	7.610	3.787	2.905			3
4					1.689	30.572	28.553	8.505	3.570	3.411			4
5					1.689	31.415	26.953	7.679	3.506	3.448			5
6					1.689	34.992	25.267	7.736	3.451	3.319			6
7					1.801	32.817	24.282	8.988	3.338	3.234			7
8					2.232	30.904	23.204	7.969	3.392	3.144			8
9					2.936	33.606	21.670	7.891	3.540	3.072			9
10					3.048	31.181	20.053	7.363	3.420	3.174			10
11					2.667	29.775	19.095	6.708	3.848	3.011			11
12					2.813	28.570	18.290	6.343	5.756	2.858			12
13					2.890	28.100	17.010	6.053	3.859	2.790			13
14					2.389	28.202	16.317	5.949	3.584	1.695			14
15					2.220	26.486	16.916	5.890	3.491	2.651			15
16					2.277	26.938	15.423	5.679	3.777	2.690			16
17					3.146	27.770	15.074	5.323	3.685	2.877			17
18					4.274	35.215	14.304	5.113	3.638	.868			18
19					5.224	34.998	13.680	5.001	4.258				19
20				1.539	5.287	37.287	13.060	4.839	3.733				20
21				1.558	6.501	38.140	12.368	4.676	3.371				21
22				1.539	9.726	39.487	12.029	4.604	3.276				22
23				1.589	12.743	39.259	12.161	4.481	3.247				23
24				1.539	16.674	38.264	11.433	4.317	3.151				24
25				1.539	20.107	36.124	10.831	4.232	3.836				25
26				1.550	19.670	35.924	10.362	4.167	5.116				26
27				1.589	14.710	34.893	10.246	4.147	4.102				27
28				1.763	15.782	33.475	9.591	4.107	3.494				28
29				2.190	16.666	31.683	9.130	4.046	3.345				29
30				2.949	16.300	31.757	8.726	4.253	3.261				30
31					14.793		8.766	4.181					31
TOTAL													
A-F				19.350	217.076	960.695	534.683	184.346	111.885	51.300			ACRE FEET
INS				.117	1.312	5.810	3.233	1.115	.676	.310			INCHES
FLOW													
MAX				2.949	20.107	39.487	31.550	8.988	5.756	3.448			MAXIMUM
MIN				.000	1.689	18.272	8.726	4.046	3.151	.000			MINIMUM

TOTAL SEASONAL RUNOFF 2079.340 ACRE FEET, 12.577 INCHES
SEASONAL PEAK DAILY FLOW 39.487 ACRE FEET, 19.908 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1968

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					1.442	11.109	24.937	8.342	4.270	3.588			1
2					1.442	14.472	23.270	7.798	4.187	3.419			2
3					1.689	19.113	22.030	7.926	5.650	3.419			3
4					1.689	22.240	20.932	7.239	5.269	3.419			4
5					1.689	29.888	20.866	8.228	5.224	3.419			5
6					1.689	32.804	19.230	9.487	5.024	3.393			6
7					1.689	30.529	17.994	8.627	4.683	3.356			7
8					1.689	30.035	17.491	7.940	4.277	3.357			8
9					1.689	27.885	16.483	9.558	3.992	3.419			9
10					1.689	24.620	16.314	9.174	3.922	3.419			10
11					1.689	23.137	15.944	8.148	3.814	3.419			11
12					1.689	29.832	15.104	7.511	3.758	3.419			12
13					1.689	37.943	14.452	7.194	3.744	3.419			13
14					1.689	36.111	13.873	8.058	3.762	3.419			14
15					1.689	36.415	13.227	7.264	4.053	3.419			15
16					1.689	41.594	12.532	6.496	4.299	1.282			16
17					1.689	44.003	12.021	6.132	4.112				17
18					1.689	48.394	11.552	5.996	4.870				18
19					1.689	48.907	11.321	5.691	4.759				19
20					1.689	52.907	10.843	5.522	4.513				20
21					2.133	52.505	10.341	5.514	4.263				21
22					3.446	49.523	10.334	5.346	4.080				22
23					3.518	46.763	10.340	5.331	4.080				23
24					3.066	44.286	9.754	5.001	3.919				24
25					2.798	39.701	9.460	4.960	3.744				25
26					2.614	34.741	9.120	4.776	3.666				26
27					2.696	34.610	8.945	5.281	3.599				27
28					3.819	34.554	9.541	5.144	3.453				28
29					5.778	32.208	9.095	5.162	3.744				29
30					7.484	28.278	9.168	4.642	3.592				30
31					9.351		9.033	4.496					31
TOTAL													
A-F					80.005	1039.120	435.563	207.997	126.337	52.590			ACRE FEET
INS					.483	6.285	2.634	1.258	.764	.318			INCHES
FLOW													
MAX					9.351	52.907	24.937	9.558	5.650	3.588			MAXIMUM
MIN					1.442	11.109	8.945	4.496	3.453	.000			MINIMUM

TOTAL SEASONAL RUNOFF 1941.615 ACRE FEET, 11.744 INCHES
SEASONAL PEAK DAILY FLOW 52.907 ACRE FEET, 26.674 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1969

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					2.762	34.368	28.750	9.247	4.623	3.863			1
2					3.361	30.283	29.877	8.822	4.478	3.683			2
3					3.959	29.777	31.685	8.583	4.480	4.052			3
4					3.820	32.702	32.087	8.369	4.516	4.080			4
5					3.689	41.562	29.488	8.002	4.310	4.080			5
6					3.909	42.864	27.011	7.516	4.086	4.091			6
7					4.513	37.832	25.062	7.141	4.170	4.269			7
8					3.252	41.959	23.128	6.781	4.049	4.029			8
9					3.307	41.019	21.997	6.601	4.223	4.020			9
10					3.795	37.198	21.080	6.370	4.356	3.961			10
11					4.405	31.924	20.059	6.484	4.164	3.842			11
12					4.683	28.562	19.341	6.650	4.108	7.711			12
13					5.048	26.789	19.177	6.492	3.933	7.031			13
14					5.434	25.861	19.852	6.012	3.894				14
15					5.621	29.026	18.931	5.676	5.077				15
16					5.631	30.924	17.574	5.632	5.660				16
17					6.430	32.163	16.625	5.584	5.279				17
18					7.600	30.772	15.794	6.218	4.623				18
19					9.455	32.290	15.641	5.827	4.273				19
20					12.816	38.651	17.971	7.659	4.184				20
21					15.108	40.711	15.317	8.569	4.108				21
22					16.946	36.699	14.071	6.368	4.313				22
23				2.470	16.844	34.296	13.137	5.691	4.162				23
24				2.799	16.791	37.511	12.378	5.338	3.964				24
25				2.612	20.819	30.571	11.819	5.047	3.888				25
26				2.220	30.067	26.767	11.377	4.938	3.744				26
27				2.085	38.412	27.146	10.913	4.765	3.744				27
28				1.949	40.599	28.442	10.337	4.839	3.744				28
29				1.786	43.126	28.747	10.549	6.084	3.643				29
30				2.113	49.434	28.419	10.341	5.837	3.877				30
31					44.743		9.805	4.978					31
TOTAL													
A-F				18.038	436.397	995.851	581.190	202.136	127.692	58.717			ACRE FEET
INS				.109	2.639	6.023	3.515	1.222	.772	.355			INCHES
FLOW													
MAX				2.799	49.434	42.864	32.087	9.247	5.660	7.711			MAXIMUM
MIN				.000	2.762	25.861	9.805	4.765	3.643	.000			MINIMUM

TOTAL SEASONAL RUNOFF 2420.024 ACRE FEET, 14.637 INCHES
SEASONAL PEAK DAILY FLOW 49.435 ACRE FEET, 24.923 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1970

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1						31.565	45.156	10.614	6.323	4.865			1
2						30.834	41.204	10.408	6.281	4.745			2
3						32.526	38.567	14.098	5.841	4.731			3
4					1.632	36.084	37.643	12.064	5.651	4.653			4
5					1.870	38.658	37.179	11.197	5.884	4.498			5
6					2.207	38.443	34.215	12.067	6.545	4.524			6
7					2.625	39.664	31.733	12.831	5.754	4.445			7
8					2.384	42.643	31.203	11.571	5.358	5.849			8
9					2.073	44.121	31.696	10.287	5.327	8.431			9
10					2.159	42.505	28.897	9.660	5.001	4.497			10
11					3.124	38.904	28.096	9.173	4.952	4.424			11
12					4.323	35.044	26.487	8.799	5.087	4.457			12
13					4.589	34.776	24.324	8.440	7.373	4.381			13
14					4.118	35.634	23.654	8.398	5.378	1.664			14
15					3.798	37.239	22.262	8.258	5.084				15
16					5.388	40.561	20.837	7.941	4.978				16
17					7.807	45.309	19.706	7.692	4.778				17
18					10.304	52.680	18.838	7.315	4.697				18
19					11.898	55.887	18.152	7.349	4.609				19
20					15.829	55.344	16.994	9.379	4.462				20
21					19.830	57.400	16.057	10.853	4.689				21
22					23.096	59.962	15.710	8.882	5.069				22
23					25.312	59.846	15.315	7.727	5.041				23
24					27.578	60.068	14.550	7.297	4.892				24
25					29.247	61.829	13.867	6.893	5.598				25
26					32.777	61.433	13.481	6.969	5.070				26
27					35.890	60.048	12.869	7.092	4.983				27
28					35.100	58.414	12.229	6.727	5.023				28
29					35.489	55.524	11.879	6.415	5.161				29
30					38.919	50.237	11.397	6.257	5.120				30
31					36.477		11.030	6.095					31
TOTAL													
A-F					425.858	1393.196	725.243	278.760	160.024	66.172			ACRE FEET
INS					2.575	8.426	4.386	1.686	.967	.400			INCHES
FLOW													
MAX					38.919	61.829	45.156	14.098	7.373	8.431			MAXIMUM
MIN					.000	30.834	11.030	6.095	4.462	.000			MINIMUM

TOTAL SEASONAL RUNOFF 3049.256 ACRE FEET, 18.443 INCHES
SEASONAL PEAK DAILY FLOW 61.830 ACRE FEET, 31.172 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
EAST ST. LOUIS CREEK 1984 ACRES

1971

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					1.032	14.085	52.631	11.316	6.366	4.099			1
2					1.233	16.775	49.898	10.842	6.265	3.953			2
3					1.653	20.675	47.928	10.307	6.229	4.080			3
4					1.845	20.274	45.840	10.090	6.583	4.164			4
5					1.663	19.572	43.443	9.664	6.997	4.064			5
6					1.442	22.375	40.920	9.186	6.730	4.067			6
7					1.496	25.376	38.507	8.850	8.402	3.992			7
8					1.674	26.056	36.643	8.467	10.555	3.772			8
9					1.442	26.317	36.712	9.057	6.088	3.779			9
10					1.442	26.376	34.480	8.773	5.366	3.623			10
11					1.442	28.503	32.423	8.197	5.047	3.443			11
12					1.666	29.221	30.818	8.599	4.960	3.419			12
13					2.311	30.386	29.829	7.945	4.649	3.412			13
14					2.680	35.335	28.533	7.498	4.642	3.271			14
15					2.701	42.482	26.845	7.242	4.664	3.143			15
16					4.247	49.202	25.365	6.918	4.686	3.162			16
17					4.967	56.278	24.086	6.855	4.646	3.245			17
18					3.825	65.355	23.999	6.742	4.871	3.129			18
19					3.575	71.261	24.519	6.937	4.988	2.954			19
20					3.419	72.360	21.884	6.496	4.837	3.868			20
21				1.023	3.705	74.500	20.914	6.103	4.778	3.275			21
22				.989	4.259	75.655	21.210	5.871	4.749	3.100			22
23				.951	4.187	77.653	19.046	6.139	4.619	3.068			23
24				.944	3.758	80.721	17.665	6.178	4.601	3.025			24
25				.859	3.906	80.761	16.619	6.261	4.468	3.040			25
26				.923	4.806	79.548	15.551	7.073	4.424	2.903			26
27				.806	7.239	76.436	14.631	7.342	4.112	1.289			27
28				.800	10.596	71.076	13.996	9.592	4.083				28
29				.785	14.133	64.290	13.344	9.120	4.055				29
30				.808	13.525	57.892	12.630	7.764	4.080				30
31					12.311		12.027	6.900					31
TOTAL													
A-F				8.892	128.196	1436.811	872.948	248.341	161.555	92.351			ACRE FEET
INS				.053	.775	8.690	5.279	1.502	.977	.558			INCHES
FLOW													
MAX				1.023	14.133	80.761	52.631	11.316	10.555	4.164			MAXIMUM
MIN				.000	1.032	14.085	12.027	5.871	4.055	.000			MINIMUM

TOTAL SEASONAL RUNOFF 2949.098 ACRE FEET, 17.837 INCHES
SEASONAL PEAK DAILY FLOW 80.761 ACRE FEET, 40.717 CUBIC FEET PER SECOND

Steamboat Springs (Park Range)

A. West Walton Creek:

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
WEST WALTON CREEK 849 ACRES

1967

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					3.915	46.139	5.336	.597	.389	.427			1
2					3.261	47.440	4.740	.499	.195	.427			2
3					2.935	43.346	4.347	.427	.151	.427			3
4					2.734	39.228	4.479	.464	.151	.754			4
5					2.531	36.223	3.821	.427	.151	.922			5
6					2.590	32.885	3.480	.427	.151	1.000			6
7					2.862	28.609	5.071	.640	.151	1.000			7
8					5.598	28.219	4.375	.996	.662	1.026			8
9					9.394	23.208	3.303	.934	.848	.817			9
10					9.531	19.974	2.588	1.066	.339	.699			10
11					9.321	18.025	2.486	.524	.198	.583			11
12					9.211	18.110	2.538	.419	.775	.427			12
13					8.413	17.341	2.051	.371	.462	.427			13
14				1.213	6.732	20.101	1.822	.307	.280	.427			14
15				2.259	5.715	21.516	1.935	.427	.379	.427			15
16				3.043	5.482	16.448	1.895	.427	.427	.388			16
17				2.350	9.519	15.842	3.830	.427	.427	.386			17
18				2.310	16.678	14.337	3.833	.427	.687	.394			18
19				3.171	24.943	14.400	1.813	.427	1.774	.389			19
20				4.177	28.720	15.998	1.498	.427	1.087	.386			20
21				3.135	33.603	13.166	1.303	.427	.691	.382			21
22				2.639	49.696	14.865	1.110	.408	.540	.355			22
23				2.315	54.047	11.622	1.051	.162	.427	.361			23
24				2.150	67.050	10.084	1.284	.148	.427	.470			24
25				1.949	60.607	10.784	1.140	.151	.427	.434			25
26				1.857	56.508	11.744	.989	.151	.455	.213			26
27				1.892	51.227	8.194	.902	.151	.462				27
28				2.523	50.235	7.718	.868	.228	.427				28
29				4.243	46.683	6.786	.720	.549	.427				29
30				5.722	43.369	5.910	.675	.581	.427				30
31					40.086		.597	.305					31
TOTAL													
A-F				46.954	723.208	618.278	75.896	13.935	14.408	13.959			ACRE FEET
INS				.663	10.222	8.738	1.072	.196	.203	.197			INCHES
FLOW													
MAX				5.722	67.050	47.440	5.336	1.066	1.774	1.026			MAXIMUM
MIN				.000	2.531	5.910	.597	.148	.151	.000			MINIMUM

TOTAL SEASONAL RUNOFF 1506.641 ACRE FEET, 21.295 INCHES
SEASONAL PEAK DAILY FLOW 67.050 ACRE FEET, 33.804 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRF FEET FOR PERIOD OF RECORD
WEST WALTON CREEK 849 ACRES

1968

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					2.955	55.146	9.824	1.350	.360	.567			1
2					4.305	64.854	8.497	1.198	.389	.567			2
3					5.489	61.574	7.579	3.248	.777	.427			3
4					7.453	60.153	6.838	1.433	1.153	.427			4
5					8.414	66.516	6.830	1.135	.744	.427			5
6					8.123	65.031	6.001	1.126	.531	.410			6
7					5.877	61.219	5.246	.861	.427	.872			7
8					4.918	54.396	5.759	.765	.427	1.383			8
9					5.369	48.876	5.087	.937	.427	1.054			9
10					7.276	46.163	4.403	1.105	.350	1.424			10
11					9.123	57.619	3.885	1.502	.293	1.740			11
12					12.543	68.113	4.117	1.256	.335	1.367			12
13					11.485	77.334	4.073	1.210	.371	1.072			13
14					8.524	70.423	3.170	6.252	.510	.844			14
15					7.454	75.828	2.919	2.229	.510	1.022			15
16					6.526	70.267	2.799	1.277	.689	.736			16
17					5.747	64.714	2.397	.961	.785				17
18				.359	5.226	58.149	2.158	1.087	1.579				18
19				.785	5.647	50.434	1.949	.872	.970				19
20				.785	7.085	44.885	1.859	.701	.648				20
21				24.830	11.066	38.636	1.832	.605	1.002				21
22				.785	17.979	32.930	1.792	.633	.864				22
23				.785	22.368	28.429	1.835	1.685	.727				23
24				.785	17.655	24.854	1.584	.931	.597				24
25				.989	13.246	20.597	1.628	.703	.761				25
26				.989	12.013	17.038	1.339	.467	.675				26
27				.371	12.569	15.294	1.833	.902	.597				27
28				.989	19.465	14.267	1.917	1.181	.597				28
29				1.189	30.298	12.711	1.347	.685	.628				29
30				1.828	38.325	11.438	2.228	.441	.570				30
31					44.663		1.649	.403					31
TOTAL													
A-F				35.473	379.199	1437.904	114.390	39.154	19.309	14.346			ACRE FEET
INS				.501	5.359	20.323	1.616	.553	.272	.202			INCHES
FLOW													
MAX				24.830	44.663	77.334	9.824	6.252	1.579	1.740			MAXIMUM
MIN				.000	2.955	11.438	1.339	.403	.293	.000			MINIMUM

TOTAL SEASONAL RUNOFF 2039.778 ACRE FEET, 28.831 INCHES
SEASONAL PEAK DAILY FLOW 77.334 ACRE FEET, 38.989 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
WEST WALTON CREEK 849 ACRES

1969

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					10.410	16.283	4.098	1.080	.601	1.403			1
2					16.128	14.025	3.717	.989	.597	1.068			2
3					22.936	12.580	3.511	.989	.556	1.468			3
4					25.663	11.612	3.504	.989	.533	1.208			4
5					27.212	10.948	3.415	.989	.597	1.208			5
6					31.044	10.754	3.079	.904	.581	1.204			6
7					30.798	10.060	2.710	.795	.528	1.335			7
8					28.870	9.374	2.397	.734	.551	1.458			8
9					33.965	8.540	2.155	.605	.617	1.462			9
10					37.837	8.227	2.053	.597	.785	1.238			10
11					41.724	9.208	1.840	.601	.665	1.208			11
12					46.944	8.906	1.751	.907	.597	1.208			12
13					45.304	7.551	1.568	.974	.597	1.442			13
14					40.299	6.594	2.887	.742	.597	1.112			14
15					35.565	10.667	2.495	.689	.733	.717			15
16					32.161	14.563	1.786	.597	1.150				16
17				2.402	39.686	11.034	1.571	.597	.576				17
18				2.843	45.135	7.718	1.442	.956	.597				18
19				3.551	50.977	6.304	1.442	1.356	.597				19
20				5.678	54.675	5.711	3.585	1.343	.597				20
21				8.102	53.532	5.150	1.934	1.319	1.890				21
22				9.964	48.001	5.251	1.506	.802	2.678				22
23				13.975	40.569	6.443	1.320	.728	1.134				23
24				26.711	37.317	11.662	1.208	.656	.902				24
25				21.644	33.582	9.387	1.122	.597	.785				25
26				16.430	31.191	8.930	1.092	.597	.777				26
27				10.738	29.034	7.409	.989	.597	.597				27
28				8.667	25.668	5.569	.989	.671	.597				28
29				8.022	23.110	5.010	2.012	1.840	.597				29
30				8.104	21.916	4.605	3.098	1.283	1.596				30
31					19.282		1.328	.821					31
TOTAL													
A-F				146.835	1060.549	270.090	67.620	27.357	24.218	18.747			ACRE FEET
INS				2.075	14.990	3.817	.955	.386	.342	.264			INCHES
FLOW													
MAX				26.711	54.675	16.283	4.098	1.840	2.678	1.468			MAXIMUM
MIN				.000	10.410	4.605	.989	.597	.528	.000			MINIMUM

TOTAL SEASONAL RUNOFF 1615.419 ACRE FEET, 22.833 INCHES
SEASONAL PEAK DAILY FLOW 54.676 ACRE FEET, 27.565 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
WEST WALTON CREEK 849 ACRES

1970

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					1.400	34.585	10.839	1.208	.989	.814			1
2					1.208	39.863	9.038	1.206	.972	.785			2
3					1.592	47.640	7.763	1.147	.887	.785			3
4					3.586	57.611	6.835	.989	.844	.785			4
5					7.663	60.478	6.585	1.101	1.021	.785			5
6					10.820	60.967	6.326	1.081	1.590	2.344			6
7					12.088	54.034	5.911	1.384	2.338	2.245			7
8					10.095	58.581	5.135	1.000	1.234	1.815			8
9					7.092	53.262	5.880	.807	.968	1.298			9
10					5.425	45.669	7.912	.742	.785	1.652			10
11					5.979	35.584	5.145	.703	.785	1.643			11
12					12.678	27.864	3.812	.597	.850	2.167			12
13					10.432	32.270	3.272	.620	1.366				13
14					11.078	33.647	2.683	.597	1.928				14
15					4.916	34.849	2.311	.597	1.194				15
16					11.466	37.720	2.082	.597	.989				16
17					27.632	39.026	1.874	.597	.887				17
18					31.625	37.526	1.934	.628	.874				18
19					35.336	35.557	2.110	.936	.785				19
20					42.950	32.003	1.978	.989	.785				20
21				.871	55.480	29.849	1.783	1.539	.843				21
22				.717	52.339	28.109	3.796	1.167	1.364				22
23				.670	51.240	25.814	8.095	.978	1.215				23
24				.633	45.937	23.685	2.425	.923	.989				24
25				.765	47.404	21.950	1.928	.989	1.085				25
26				1.653	51.627	20.100	1.748	.989	1.012				26
27				2.911	57.030	18.307	1.843	.989	.989				27
28				3.675	44.618	16.716	1.730	1.067	.963				28
29				2.270	36.478	15.570	1.599	.989	.891				29
30				1.592	43.973	13.032	1.643	.902	.793				30
31					39.672		1.760	.810					31
TOTAL													
A-F				15.762	780.874	1071.881	127.788	28.882	32.229	17.123			ACRE FEET
INS				.222	11.037	15.150	1.806	.408	.455	.242			INCHES
FLOW													
MAX				3.675	57.030	60.967	10.839	1.539	2.338	2.344			MAXIMUM
MIN				.000	1.208	13.032	1.599	.597	.785	.000			MINIMUM

TOTAL SEASONAL RUNOFF 2074.543 ACRE FEET, 29.322 INCHES
SEASONAL PEAK DAILY FLOW 60.967 ACRE FEET, 30.737 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
WEST WALTON CREEK 849 ACRES

1971

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					5.895	35.111	13.201	1.208	.427	.598			1
2					8.564	43.698	11.823	1.208	.427	.583			2
3					12.100	52.603	10.784	1.208	.504	.623			3
4					15.527	44.096	9.778	1.208	.885	.679			4
5					13.776	43.399	8.773	1.112	1.132	.612			5
6					13.041	45.281	8.095	.989	.940	.549			6
7					14.315	54.929	7.457	.989	1.443	.427			7
8					13.874	56.579	7.395	.987	1.531	.155			8
9					12.971	57.766	6.665	.985	.829				9
10					10.801	55.587	5.859	.966	.710				10
11					10.595	54.207	5.112	.910	.597				11
12					14.631	57.127	4.611	.989	.597				12
13					21.483	61.656	4.170	.970	.597				13
14					30.955	65.619	3.849	.986	.590				14
15				8.867	35.456	61.518	3.546	.846	.574				15
16				11.152	37.961	57.656	3.279	.785	.446				16
17				11.888	31.943	53.579	3.084	.427	.624				17
18				10.760	22.873	47.155	2.938	.427	.697				18
19				9.561	17.767	43.750	3.309	.427	.720				19
20				7.643	14.704	40.412	2.906	.427	.726				20
21				6.247	14.811	37.108	3.456	.427	.779				21
22				5.339	19.724	34.477	3.244	.427	.751				22
23				4.880	19.470	31.953	2.700	.427	.582				23
24				5.726	19.358	29.262	2.430	.427	.427				24
25				6.133	25.416	26.555	2.327	.427	.419				25
26				6.631	32.561	24.018	2.152	.427	.277				26
27				5.604	44.628	21.657	1.949	.427	.277				27
28				5.141	52.872	19.176	1.946	.441	.277				28
29				4.918	62.317	17.931	1.794	.749	.277				29
30				4.750	55.917	15.136	1.703	.597	.380				30
31					37.649		1.689	.537					31
TOTAL													
A-F				115.248	743.970	1289.015	152.038	23.382	19.457	4.230			ACRE FEET
INS				1.628	10.515	18.219	2.148	.330	.275	.059			INCHES
FLOW													
MAX				11.888	62.317	65.619	13.201	1.208	1.531	.679			MAXIMUM
MIN				.000	5.895	15.136	1.689	.427	.277	.000			MINIMUM

TOTAL SEASONAL RUNOFF 2347.343 ACRE FEET, 33.178 INCHES
SEASONAL PEAK DAILY FLOW 65.619 ACRE FEET, 33.083 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
NORTH FISH CREEK 1435 ACRES

B. North Fish Creek:

1967

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1						57.468	110.489	2.546	1.244	1.236			1
2						82.581	92.556	2.700	.655	1.681			2
3						104.789	73.962	2.297	.471	1.236			3
4						101.462	83.605	2.077	.448	1.447			4
5						106.161	66.204	1.598	.324	1.654			5
6						106.919	52.359	1.651	.450	2.266			6
7						105.805	68.361	6.312	.460	2.311			7
8						98.986	49.007	3.926	.897	4.109			8
9						86.158	35.982	2.593	1.130	3.185			9
10					6.264	89.741	27.071	2.615	.746	2.363			10
11					5.181	94.385	24.749	2.862	2.784	1.822			11
12					3.929	85.799	19.922	2.084	5.214	1.578			12
13					3.749	78.886	15.872	1.566	1.551	1.429			13
14					3.241	85.263	14.206	1.340	1.354	1.499			14
15					2.872	70.593	16.109	1.684	1.493	1.294			15
16					3.192	76.530	13.303	1.478	2.235	1.058			16
17					5.046	97.070	39.145	1.280	1.964	1.511			17
18					9.550	137.886	24.065	1.034	3.492	1.436			18
19					14.612	152.034	13.755	.981	5.770	1.252			19
20					20.005	167.709	10.294	1.236	3.136	1.119			20
21					26.406	146.863	8.057	1.236	2.033	1.117			21
22					38.927	157.245	6.759	1.016	1.669	1.055			22
23					58.404	149.826	9.877	.810	1.453	.929			23
24					71.223	148.361	10.670	.644	1.652	1.070			24
25					89.412	153.852	6.746	.598	1.896	.675			25
26					91.876	147.928	4.974	.554	1.803				26
27					78.775	145.604	4.197	.497	1.529				27
28					75.612	106.508	3.372	.491	1.391				28
29					69.826	118.742	2.896	1.344	1.236				29
30					63.827	120.999	2.547	1.193	1.236				30
31					55.735		2.574	1.386					31
TOTAL													
A-F					797.673	3382.169	913.699	53.644	51.733	40.346			ACRE FEET
INS					6.670	28.282	7.640	.448	.432	.337			INCHES
FLOW													
MAX					91.876	167.709	110.489	6.312	5.770	4.109			MAXIMUM
MIN					.000	57.468	2.547	.491	.324	.000			MINIMUM

TOTAL SEASONAL RUNOFF 5239.267 ACRE FEET, 43.813 INCHES
SEASONAL PEAK DAILY FLOW 167.709 ACRE FEET, 84.552 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
NORTH FISH CREEK 1435 ACRES

1968

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1						70.424	104.666	7.179	1.119	.746			1
2						81.627	107.790	4.035	1.034	.746			2
3						89.788	106.016	6.134	3.189	.726			3
4						90.889	104.128	3.653	3.359	.737			4
5						103.449	86.438	2.820	1.911	.864			5
6						108.380	82.304	2.843	1.294	.746			6
7						111.337	73.519	2.460	1.042	1.262			7
8						93.849	60.493	2.124	.881	1.602			8
9					5.336	72.311	60.522	3.512	.795	1.513			9
10					6.421	59.478	59.499	3.303	.680	.604			10
11					8.676	49.103	48.223	5.492	.651				11
12					11.121	72.090	39.362	3.820	.728				12
13					10.428	105.678	33.738	5.134	.746				13
14					8.520	114.878	26.345	13.911	1.052				14
15					7.091	130.965	22.297	8.155	1.171				15
16					6.143	135.744	17.899	4.233	1.365				16
17					5.468	134.953	14.338	3.067	1.511				17
18					5.189	155.574	11.608	4.802	4.047				18
19					5.627	154.146	9.846	2.796	1.781				19
20					6.105	176.656	8.690	2.412	1.152				20
21					8.662	177.395	16.376	2.436	2.440				21
22					16.247	176.600	8.280	2.274	2.264				22
23					21.790	166.677	8.609	3.363	1.574				23
24					16.212	145.930	6.235	2.400	1.236				24
25					11.787	123.754	5.455	1.568	1.029				25
26					9.754	137.095	5.103	1.376	.981				26
27					9.715	170.710	4.455	1.663	.851				27
28					16.366	169.341	4.109	2.201	.746				28
29					31.078	163.600	3.700	3.270	.746				29
30					45.695	107.961	8.982	1.848	.746				30
31					57.530		5.658	1.355					31
TOTAL													
A-F					330.973	3650.396	1154.700	115.653	42.136	9.551			ACRE FEET
INS					2.767	30.525	9.656	.967	.352	.079			INCHES
FLOW													
MAX					57.530	177.395	107.790	13.911	4.047	1.602			MAXIMUM
MIN					.000	49.103	3.700	1.355	.651	.000			MINIMUM

TOTAL SEASONAL RUNOFF 5303.412 ACRE FEET, 44.349 INCHES
SEASONAL PEAK DAILY FLOW 177.396 ACRE FEET, 89.436 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD

NORTH FISH CREEK 1435 ACRES

1969

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					10.784	86.924	36.890	3.233	.881	4.496			1
2					15.757	89.211	32.860	2.504	.829	2.857			2
3					22.947	95.059	32.695	2.357	.693	3.546			3
4					26.639	110.898	30.340	2.070	.788	3.498			4
5					26.541	143.953	43.059	1.825	.713	3.606			5
6					26.111	138.131	25.777	1.775	.651	3.809			6
7					28.819	124.474	18.366	1.461	.618	4.159			7
8					24.007	132.103	14.922	1.304	.609	4.352			8
9					31.521	128.917	12.409	1.153	.745	3.803			9
10					43.298	89.946	10.460	1.111	6.520	3.498			10
11					50.688	62.168	8.964	1.120	1.799	3.498			11
12					53.564	59.746	7.746	4.672	1.122	3.498			12
13					61.271	66.686	6.799	2.429	1.421	3.498			13
14					60.120	72.717	8.984	2.930	1.548	3.498			14
15					50.273	70.537	8.711	2.243	2.147	2.113			15
16					39.498	101.729	5.732	1.103	2.451				16
17					44.441	81.451	4.715	1.098	1.960				17
18					68.681	84.484	4.593	2.131	1.320				18
19					84.758	88.816	4.435	1.649	1.049				19
20					89.909	84.227	25.842	4.628	.981				20
21					94.413	82.022	8.811	2.563	1.712				21
22					105.218	73.195	5.330	1.408	7.738				22
23				8.888	105.183	63.364	4.180	1.122	4.941				23
24				13.167	110.695	98.652	3.465	1.055	2.508				24
25				16.195	125.222	46.989	3.029	.952	1.675				25
26				13.771	134.403	39.897	2.598	.866	1.393				26
27				10.920	132.909	60.465	2.216	.868	1.180				27
28				8.313	130.907	69.441	1.957	.998	1.119				28
29				8.226	142.815	48.134	6.028	2.550	.981				29
30				9.029	144.873	40.334	17.594	1.611	7.892				30
31					119.305		5.758	1.114					31
TOTAL													
A-F				88.512	2205.587	2534.684	405.279	57.919	59.999	53.735			ACRE FEE
INS				.740	18.443	21.195	3.389	.484	.501	.449			INCHES
FLOW													
MAX				16.195	144.873	143.953	43.059	4.672	7.892	4.496			MAXIMUM
MIN				.000	10.784	39.897	1.957	.866	.609	.000			MINIMUM

TOTAL SEASONAL RUNOFF 5405.718 ACRE FEET, 45.205 INCHES

SEASONAL PEAK DAILY FLOW 144.874 ACRE FEET, 73.040 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD

NORTH FISH CREEK 1435 ACRES

1970

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1						65.234	138.107	4.007	.981	1.529			1
2						75.055	132.313	3.710	1.029	1.511			2
3						93.462	125.746	3.567	1.018	1.496			3
4						107.282	125.841	3.536	.939	1.459			4
5						116.532	113.869	4.689	2.197	1.491			5
6						109.740	119.041	3.634	3.522	2.328			6
7						105.159	89.183	6.146	6.236	3.211			7
8						130.732	75.182	4.137	18.110				8
9						127.486	71.998	3.026	8.068				9
10						102.440	61.730	2.518	3.517				10
11						63.455	49.608	2.288	2.227				11
12					11.046	45.852	40.634	2.135	3.430				12
13					11.290	43.253	33.755	2.040	4.105				13
14					10.234	56.481	27.556	1.980	2.521				14
15					8.574	58.565	22.434	1.999	2.021				15
16					10.420	63.753	18.539	1.957	1.855				16
17					19.665	90.968	16.116	2.342	1.690				17
18					29.314	124.090	14.116	2.216	1.493				18
19					43.657	139.316	21.636	1.864	1.405				19
20					52.704	147.886	15.289	2.167	1.268				20
21					62.260	159.204	12.632	2.830	1.751				21
22					63.315	167.508	17.986	2.066	3.713				22
23					63.464	184.582	23.677	1.719	3.835				23
24					68.890	190.658	11.104	1.524	3.192				24
25					72.575	197.630	9.180	1.408	2.892				25
26					85.219	196.571	9.848	1.431	3.332				26
27					98.428	199.964	8.445	1.511	2.803				27
28					86.631	223.357	6.901	1.119	2.250				28
29					69.407	193.653	5.972	1.106	2.005				29
30					84.655	160.453	5.190	.981	1.733				30
31					82.664		4.652	.949					31
TOTAL													
A-F					1034.419	3740.340	1428.293	76.615	95.151	13.028			ACRE FEET
INS					8.650	31.278	11.943	.640	.795	.108			INCHES
FLOW													
MAX					98.428	223.357	138.107	6.146	18.110	3.211			MAXIMUM
MIN					.000	43.253	4.652	.949	.939	.000			MINIMUM

TOTAL SEASONAL RUNOFF 6387.850 ACRE FEET, 53.418 INCHES

SEASONAL PEAK DAILY FLOW 223.357 ACRE FEET, 112.608 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
NORTH FISH CREEK 1435 ACRES

1971

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					4.984	38.398	135.524	3.946	.876				1
2					6.831	41.610	129.601	4.355	.920				2
3					10.868	54.073	124.676	7.122	1.206				3
4					14.498	55.909	102.849	15.830	1.942				4
5					12.708	46.916	100.243	8.810	6.804				5
6					11.183	60.638	79.757	4.479	2.501				6
7					11.679	78.506	81.013	3.528	6.499				7
8					10.735	97.793	69.051	3.023	3.956				8
9					10.018	86.203	63.538	3.432	1.838				9
10					9.084	83.842	56.363	3.446	1.321				10
11					8.426	86.911	48.396	2.619	1.117				11
12					9.851	103.806	41.580	3.831	.903				12
13					15.484	119.648	35.896	2.971	.871				13
14					24.897	137.254	31.085	2.432	.788				14
15					30.936	155.022	20.637	2.057	.746				15
16					38.819	160.449	10.661	1.836	.746				16
17					35.718	171.533	8.107	1.716	.758				17
18					25.842	163.084	7.596	1.797	1.519				18
19					19.446	177.726	18.864	1.735	1.236				19
20					15.991	182.344	8.618	1.547	1.380				20
21					14.724	186.005	7.142	1.556	1.675				21
22				5.091	16.622	172.134	11.736	1.705	2.048				22
23				4.689	19.374	195.630	16.653	1.445	.791				23
24				4.777	17.950	203.440	12.862	1.484					24
25				5.221	22.857	195.869	9.685	1.433					25
26				5.641	37.883	195.412	8.134	1.264					26
27				5.144	58.454	200.528	6.958	1.698					27
28				4.694	69.224	189.691	6.056	1.364					28
29				4.486	79.418	160.944	5.465	1.671					29
30				4.350	72.213	155.244	4.894	1.130					30
31					46.181		4.306	1.084					31
TOTAL													
A-F				44.097	782.916	3956.575	1267.963	96.363	42.451				ACRE FEET
INS				.368	6.547	33.086	10.603	.805	.354				INCHES
FLOW													
MAX				5.641	79.418	203.440	135.524	15.830	6.804				MAXIMUM
MIN				.000	4.984	38.398	4.306	1.084	.000				MINIMUM

TOTAL SEASONAL RUNOFF 6190.368 ACRE FEET, 51.766 INCHES
SEASONAL PEAK DAILY FLOW 203.440 ACRE FEET, 102.566 CUBIC FEET PER SECOND

C. South Soda Creek:

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
SOUTH SODA CREEK 2174 ACRES

1967

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					12.429	101.184	77.700	2.153	.831	.312			1
2					10.354	141.538	64.158	1.635	.534	.374			2
3					9.010	156.953	52.522	1.954	.462	.306			3
4					8.069	144.517	56.296	1.727	.274	.395			4
5				4.785	7.412	149.675	46.465	1.350	.234	.493			5
6				5.374	7.198	150.186	37.712	1.233	.158	1.104			6
7				7.775	7.606	138.178	55.100	4.428	.154	1.192			7
8				10.533	14.296	121.799	42.198	3.999	.521	1.771			8
9				10.335	24.802	107.339	30.126	2.149	.999	1.895			9
10				9.650	26.923	106.817	23.135	2.295	.640	1.457			10
11				14.308	21.506	104.504	20.983	1.799	1.079	1.167			11
12				15.685	19.558	94.967	17.813	1.638	3.286	1.095			12
13				11.612	18.856	94.477	15.157	1.393	1.368	1.029			13
14				9.340	14.924	105.147	13.329	1.043	.811	.966			14
15				8.495	12.544	87.776	14.136	.779	.612	.976			15
16				7.834	11.929	92.522	13.022	.664	.687	.853			16
17				7.392	20.915	110.448	28.994	.543	.846	.719			17
18				8.538	40.417	145.478	28.379	.296	1.135	.655			18
19				11.341	57.285	152.329	14.792	.188	2.582	.551			19
20				15.366	63.873	175.626	11.034	.347	2.057	.440			20
21				11.408	79.963	141.248	8.583	.534	1.046	.415			21
22				9.460	111.652	144.549	7.168	.534	.744	.391			22
23				8.075	133.149	133.722	9.370	.473	.499	.489			23
24				7.119	151.880	125.968	10.403	.411	.606	.495			24
25				6.418	178.693	126.243	7.113	.347	.930	.399			25
26				5.973	186.286	119.260	5.288	.264	.917	.236			26
27				6.240	157.100	111.829	4.322	.261	.856				27
28				8.712	158.479	86.806	3.399	.271	.587				28
29				14.888	132.085	86.265	2.866	.546	.395				29
30				16.972	113.107	85.298	2.352	.821	.313				30
31					95.150		2.274	.618					31
TOTAL													
A-F				253.640	1907.465	3642.662	726.199	36.710	26.178	20.188			ACRE FEET
INS				1.400	10.528	20.106	4.008	.202	.144	.111			INCHES
FLOW													
MAX				16.972	186.286	175.626	77.700	4.428	3.286	1.895			MAXIMUM
MIN				.000	7.198	85.298	2.274	.188	.154	.000			MINIMUM

TOTAL SEASONAL RUNOFF 6613.045 ACRE FEET, 36.503 INCHES
SEASONAL PEAK DAILY FLOW 186.286 ACRE FEET, 93.918 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
SOUTH SODA CREEK 2174 ACRES

1968

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					16.045	131.584	80.568	4.837	.597	.434			1
2					23.465	148.461	81.114	2.648	.340	.376			2
3					29.755	151.693	78.183	2.631	1.091	.292			3
4					37.627	154.561	75.965	1.951	1.799	.305			4
5					36.854	177.223	66.318	1.432	1.307	.325			5
6					28.947	169.242	57.565	1.369	.703	.310			6
7					20.687	156.136	50.908	1.353	.412	.681			7
8					16.562	127.052	43.431	1.236	.528	1.333			8
9					17.672	94.551	41.711	2.170	.586	1.173			9
10					23.969	79.399	41.213	2.078	.450	1.159			10
11					33.290	78.897	36.339	2.385	.417	1.932			11
12					39.494	121.018	30.955	2.403	.520	2.653			12
13					31.674	166.153	25.293	2.488	.539	2.369			13
14					23.180	168.923	20.579	10.528	.382	1.647			14
15					18.761	188.236	17.809	6.695	.534	2.747			15
16					16.283	182.224	14.436	3.462	.518	2.478			16
17				4.711	14.371	176.871	11.669	2.076	.746	.696			17
18				4.755	13.689	185.114	9.577	2.287	1.154				18
19				5.060	15.119	191.134	8.110	1.616	.840				19
20				4.681	18.240	213.705	7.122	1.175	.350				20
21				4.570	34.581	199.389	6.210	1.125	1.023				21
22				4.274	59.118	192.021	6.487	.859	1.327				22
23				4.097	53.182	170.664	6.649	2.136	1.178				23
24				4.023	36.080	148.259	4.607	1.647	.898				24
25				3.879	28.527	119.997	3.769	.799	.678				25
26				3.716	26.061	124.223	3.225	.584	.594				26
27				3.498	32.264	150.286	2.834	.630	.421				27
28				3.542	56.248	143.341	2.444	1.161	.432				28
29				4.480	87.110	132.264	2.111	1.976	.423				29
30				8.372	100.157	90.006	4.381	1.273	.440				30
31					120.215		3.985	.829					31
TOTAL													
A-F				63.665	1109.242	4532.642	845.585	69.852	21.243	20.918			ACRE FEET
INS				.351	6.122	25.019	4.667	.385	.117	.115			INCHES
FLOW													
MAX				8.372	120.215	213.705	81.114	10.528	1.799	2.747			MAXIMUM
MIN				.000	13.689	78.897	2.111	.584	.340	.000			MINIMUM

TOTAL SEASONAL RUNOFF 6663.148 ACRE FEET, 36.779 INCHES
SEASONAL PEAK DAILY FLOW 213.706 ACRE FEET, 107.742 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
SOUTH SODA CREEK 2174 ACRES

1969

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					35.424	81.019	33.501	4.288	.452	4.261			1
2				3.606	55.074	80.653	29.495	3.129	.398	3.124			2
3				3.618	64.380	82.999	28.227	2.868	.366	4.146			3
4				3.920	62.094	88.950	26.059	2.707	.337	4.631			4
5				4.871	61.206	111.739	35.274	2.193	.370	5.102			5
6				8.137	75.494	106.208	25.012	1.894	.267	5.490			6
7				9.821	81.975	97.395	18.568	1.441	.239	6.820			7
8				7.722	63.129	98.861	15.587	1.140	.228	7.462			8
9				7.379	77.771	90.978	13.038	.947	.331	6.204			9
10				9.586	92.788	68.258	11.097	.835	4.038	5.530			10
11				12.929	100.582	52.898	9.427	.862	1.453	5.973			11
12				13.884	105.946	54.360	8.159	3.041	.665	5.530			12
13				11.275	110.702	55.847	7.227	2.573	.674	5.100			13
14				12.283	103.132	53.850	10.471	1.249	1.164	5.100			14
15				14.153	87.063	54.141	8.878	.890	1.209	2.921			15
16				11.348	74.060	84.089	5.712	.760	1.905				16
17				10.333	82.886	72.698	4.774	.717	1.464				17
18				11.509	114.785	62.232	4.622	1.922	.881				18
19				13.864	134.580	60.378	4.248	1.792	.621				19
20				21.629	128.656	58.119	17.220	3.356	.526				20
21				30.014	132.212	54.717	9.488	2.990	1.186				21
22				44.444	146.126	54.940	5.677	1.515	7.584				22
23				57.244	134.426	46.234	4.519	1.052	5.454				23
24				62.583	134.376	88.416	3.736	.977	3.234				24
25				52.481	149.661	57.995	3.319	.879	2.155				25
26				34.692	152.297	48.203	2.735	.562	1.634				26
27				25.064	140.364	65.816	2.286	.426	1.333				27
28				19.524	134.429	67.250	1.943	.454	1.075				28
29				18.559	142.830	48.612	5.158	1.369	.942				29
30				22.457	134.473	38.937	15.254	1.362	5.340				30
31					108.512		7.070	.768					31
TOTAL													
A-F				558.946	3221.447	2086.807	377.795	50.973	47.540	77.400			ACRE FEET
INS				3.085	17.781	11.518	2.085	.281	.262	.427			INCHES
FLOW													
MAX				62.583	152.297	111.739	35.274	4.288	7.584	7.462			MAXIMUM
MIN				.000	35.424	38.937	1.943	.426	.228	.000			MINIMUM

TOTAL SEASONAL RUNOFF 6420.912 ACRE FEET, 35.442 INCHES
SEASONAL PEAK DAILY FLOW 152.297 ACRE FEET, 76.782 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
SOUTH SODA CREEK 2174 ACRES

1970

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					6.904	96.432	93.355	1.859	.097	.601			1
2					6.592	114.369	86.125	1.555	.162	.465			2
3					8.024	138.673	81.599	1.461	.114	.439			3
4					13.394	156.585	79.699	1.305	.069	.454			4
5					23.281	162.827	70.786	1.552	.305	.467			5
6					33.071	152.305	79.565	1.168	1.541	2.189			6
7					36.811	149.986	66.547	2.055	3.768	3.171			7
8					30.252	170.418	49.706	1.633	7.235	2.454			8
9					21.599	155.552	50.461	.983	4.529	2.489			9
10					17.981	131.761	44.554	.677	2.071	3.255			10
11					24.950	92.966	34.186	.478	1.146	3.498			11
12					35.666	68.259	28.149	.298	1.013	5.054			12
13					34.075	73.974	22.932	.267	2.466	3.302			13
14					28.587	91.351	18.858	.286	1.373				14
15					24.398	89.658	15.428	.292	1.116				15
16				4.196	40.203	100.238	12.547	.254	.840				16
17				3.879	73.217	128.299	10.705	.318	.683				17
18				3.879	90.899	158.745	9.225	.429	.555				18
19				3.879	101.721	165.973	13.448	.291	.400				19
20				3.685	119.251	167.393	10.407	.306	.378				20
21				3.746	128.130	187.287	7.625	.810	.642				21
22				4.069	119.515	184.040	9.806	.394	1.408				22
23				3.456	117.805	189.898	12.956	.226	1.893				23
24				3.310	124.931	185.369	7.006	.120	1.749				24
25				3.944	127.937	185.984	5.536	.088	1.611				25
26				6.818	148.881	174.798	6.475	.000	1.415				26
27				11.797	163.048	167.622	5.555	.000	1.322				27
28				13.911	133.343	169.009	4.104	.079	1.062				28
29				9.559	108.252	143.525	3.311	.123	.863				29
30				7.804	139.284	113.308	2.740	.048	.783				30
31					122.150		2.250	.059					31
TOTAL													
A-F				87.938	2204.167	4266.619	945.662	19.427	42.627	27.845			ACRE FEET
INS				.485	12.166	23.550	5.219	.107	.235	.153			INCHES
FLOW													
MAX				13.911	163.048	189.898	93.355	2.055	7.235	5.054			MAXIMUM
MIN				.000	6.592	68.259	2.250	.000	.069	.000			MINIMUM

TOTAL SEASONAL RUNOFF 7594.289 ACRE FEET, 41.919 INCHES
SEASONAL PEAK DAILY FLOW 189.899 ACRE FEET, 95.739 CUBIC FEET PER SECOND

STREAMFLOW SUMMARY IN ACRE FEET FOR PERIOD OF RECORD
SOUTH SODA CREEK 2174 ACRES

1971

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DAY
1					14.988	65.972	94.022	2.069	.066	.925			1
2					25.763	73.291	89.215	1.976	.066	.753			2
3					43.742	86.813	84.150	2.363	.082	.965			3
4					48.372	84.852	71.312	2.853	.333	1.718			4
5					38.179	76.803	65.835	3.085	.962	1.922			5
6					33.155	93.903	53.825	1.650	.876	1.595			6
7					35.275	121.047	52.291	1.371	2.099	1.177			7
8					30.459	132.990	46.633	1.149	2.331	.508			8
9					26.106	124.413	42.419	1.247	.672				9
10					21.390	115.928	37.332	1.310	.347				10
11					20.608	112.416	32.544	.900	.241				11
12					31.969	136.319	28.411	.968	.188				12
13				19.926	53.807	151.140	25.159	1.120	.188				13
14				27.821	73.076	178.491	22.197	.840	.140				14
15				33.730	81.222	198.358	18.870	.585	.066				15
16				36.768	91.357	190.950	15.516	.534	.066				16
17				35.587	72.690	203.066	12.996	.534	.186				17
18				28.001	46.762	183.649	12.359	.249	.277				18
19				25.149	35.488	195.786	15.040	.120	.297				19
20				20.211	29.434	196.953	11.499	.079	.366				20
21				16.342	29.179	193.632	9.479	.145	.384				21
22				14.102	37.790	199.678	10.413	.066	.427				22
23				12.386	39.516	185.758	9.397	.066	.652				23
24				13.021	35.105	185.289	7.921	.084	1.020				24
25				14.999	49.456	170.584	6.122	.097	1.169				25
26				16.567	80.043	159.535	5.022	.066	.949				26
27				13.797	113.504	153.185	4.126	.076	.519				27
28				11.943	131.597	140.001	3.482	.122	.376				28
29				11.325	149.780	117.844	3.112	.117	.347				29
30				11.152	119.912	109.894	2.655	.066	.716				30
31					72.379		2.294	.066					31
TOTAL													
A-F				362.835	1712.115	4338.553	895.661	25.988	16.423	9.565			ACRE FEET
INS				2.002	9.450	23.947	4.943	.143	.090	.052			INCHES
FLOW													
MAX				36.768	149.780	203.066	94.022	3.085	2.331	1.922			MAXIMUM
MIN				.000	14.988	65.972	2.294	.066	.066	.000			MINIMUM

TOTAL SEASONAL RUNOFF 7361.144 ACRE FEET, 40.632 INCHES
SEASONAL PEAK DAILY FLOW 203.067 ACRE FEET, 102.378 CUBIC FEET PER SECOND

Leaf, Charles F., and Glen E. Brink.
1972. Annual streamflow summaries from four subalpine watersheds in Colorado. USDA For. Serv. Gen. Tech. Rep. RM-1, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Streamflow runoff summaries are presented for four experimental watersheds near Fraser and Steamboat Springs, Colorado. Interval of published record varies from 1943-71 at Fraser to 1967-71 at Steamboat Springs.

Keywords: Demonstration watersheds, Fraser Experimental Forest, snowmelt, streamflow, subalpine watersheds, surface waters.

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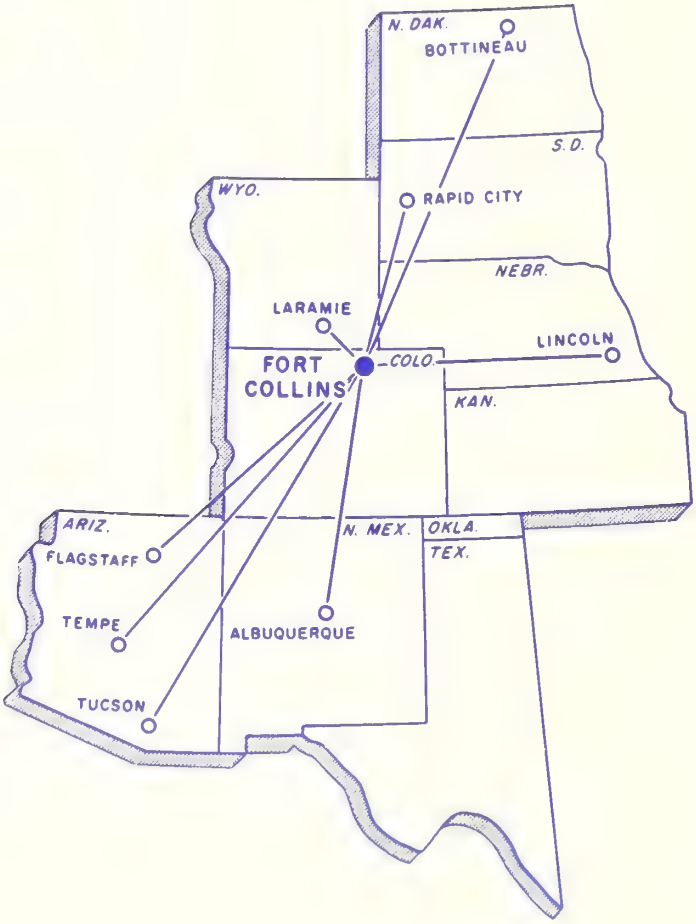
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THE BLACK HILLS (South Dakota) FLOOD OF JUNE 1972: IMPACTS AND IMPLICATIONS

by **Howard K. Orr**

USDA Forest Service
General Technical Report RM-2

March 1973

Rocky Mountain Forest and Range Experiment Station
Forest Service
U.S. Department of Agriculture

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Abstract

Rains of 12 inches or more in 6 hours fell on the east slopes of the Black Hills the night of June 9, 1972. Resulting flash floods exacted a disastrous toll in human life and property. Rainfall and discharge so greatly exceeded previous records that recurrence intervals have been presented in terms of multiples of the estimated 50- or 100-year event. Quick runoff was produced in the heaviest rainfall areas regardless of hydrologic condition. Flood sources included all major geologic and soil types and practically all land uses in the Black Hills. The highest measured peak runoff per unit area came from a 7-square-mile drainage, all on sedimentary formations, the upper portion of which burned over in 1936, but which is now well vegetated, apparently stable, and in good hydrologic condition. Greatest damage occurred where man-origin debris piled up against bridges, highways, homes, and other improvements.

Keywords: Floods, watershed management, hydrologic data, flash floods, storm runoff, record rainfall.

USDA Forest Service
General Technical Report RM-2

March 1973

The Black Hills (South Dakota) Flood of June 1972: Impacts and Implications

by
Howard K. Orr, Hydrologist

Rocky Mountain Forest and Range Experiment Station[1]

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[1] *Research reported here was conducted at Station's Research Work Unit at Rapid City, in cooperation with South Dakota School of Mines and Technology; central headquarters is maintained at Fort Collins in cooperation with Colorado State University.*

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The Black Hills (South Dakota) Flood of June 1972: Impacts and Implications

Howard K. Orr

The Black Hills storm and flash floods of June 9, 1972 will long be remembered — not only for the tragic loss of life and property but also as a hydrologic event of such magnitude and rarity that the recurrence interval is more than ordinarily problematical. It also has provided a unique opportunity for land managers and researchers to study and observe environmental and land management responses and implications under the stress of a rare storm event.

The purpose of this report is to examine and describe physical factors and relationships involved in the production of excessive flood flows from a number of Black Hills drainages on June 9, including the Sturgis Experimental Watersheds, and to postulate supporting theory.

The Storm

The storm was concentrated in an area about 40 miles long by 20 miles wide. The area includes downstream portions of nearly all the watersheds draining east out of the Black Hills from Bear Butte Creek on the north to Iron Creek (tributary to Battle Creek) on the south (fig. 1).

According to recording gages on the Sturgis Experimental Watersheds (in the northern part of storm area, fig. 1), precipitation began at about 1450 (m.s.t.), and gradually built up to a maximum intensity of nearly 6 inches per hour about 1630. Rain continued steadily but at gradually declining intensity until between 0200 and 0230 on June 10.

At the Black Hills Experimental Forest, about 15 miles south and slightly west, the storm began between 1600 and 1615. Less rain fell (total was 5.82 inches in one gage) than either to the northeast or southeast, but rainfall ended at about the same time (by 0230 on June 10). At Rochford, about 5 miles further southwest, total storm precipitation was only 1.77 inches.

At Pactola Dam, about 12 airline miles east of the Experimental Forest and slightly further south (about halfway along the north to south axis of the storm but still slightly west of the approximate north-south line of heaviest precipitation cells), light rainfall started between 1400 and 1500. Maximum rain fell between 2000 and 2100 (1.83 inches) and by midnight 6.86 inches had accumulated. The maximum 6-hour precipitation, 6.30 inches, fell between 1700 and 2300. The storm ended there between 0200 and 0300, after 7.03 inches of rain fell.

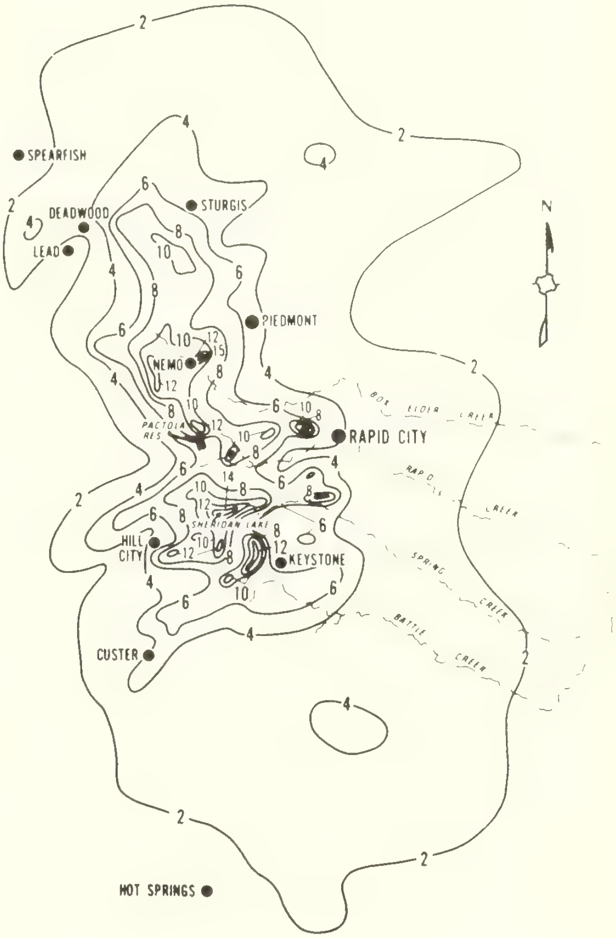

Figure 1.--Total rainfall during evening of June 9 into morning of June 10, 1972 (U. S. Department of Commerce 1972).

The best available information from locations further east, and nearer the apparent center of heavy precipitation cells in the Rapid Creek drainage, indicates rainfall started about 1900 and accumulated to 13 inches by 0700 on

June 10. Nearly 12 inches of rain fell in 6 hours (about 1930 June 9 to 0130 June 10).

Putting these facts together, the heavy rainfall obviously started earliest in the northern Hills. As separate cells fed in on strong east and southeast winds, the storm built to larger and larger proportions as it spread southward.

H. J. Thompson, Office of Hydrology, National Weather Service, described the general meteorological circumstances in which the storm developed (Thompson 1972, p. 163). Strong low-level winds from the east forced moist air upslope on the east side of the Hills. Sustained orographic effect helped force the air to rise and cool as it fed in from the east. At the same time, midlevel moisture was impinging from the south. Another especially significant contributing factor was the unusually light wind at higher atmospheric levels which did not disperse the moisture or move the thunderstorms eastward as rapidly as usual. The result was repeating thunderstorms in an apparently unusual combination of meteorological conditions. Under "reverse shear" conditions (St. Amand et al. 1972), an almost continuous line of thunderstorms formed and remained quasi-stationary over the eastern Hills for as long as 6 to 8 hours, whereas the more ordinary thunderstorm moves out in 1 to 2 hours.

Thompson (1972) asserts that the recurrence interval of such an extraordinary event cannot be computed with any degree of accuracy, but adds in effect that the measured rainfall was in an amount **unlikely** to occur more than once in several thousand years. In a report from the National Oceanic and Atmospheric Administration, (U.S. Department of Commerce 1972) it is stated that the 6-hour rainfall averaged about four times the amount to be expected once every 100 years.

Hydrologic Condition

In all of the most heavily flooded watersheds examined, there was consistent evidence of surface runoff from slope areas even where there were no clearly visible drainage patterns, and further upslope than in the case of more ordinary storms. The consistency of this kind of evidence, irrespective of site, is a key factor in analyzing the production of the flood flow. Surface runoff occurred from all types of areas, including dense forest and well-grassed slopes. In other words, classification in "good" hydrologic condition did not in this case preclude the production of excessive surface runoff. Surface runoff is here differentiated from overland flow in the sense that surface runoff was evident in shallow depressions of microtopography not ordinarily observed, but there was little evidence of sheet movement of water that resulted in sheet movement of soil or its protective cover of litter and humus. This is a generalization that applied across forest types and densities, other vegetation types, slopes, topography, parent materials, geology, and soils. Thick forest floor, where present, apparently acted as an efficient water conveyance system, but without displacement except where water was diverted or concentrated by stones, roots, or other obstacles (fig. 2). The storm and runoff produced were obviously of a magnitude that plays a major role in shaping topography as we see it today.

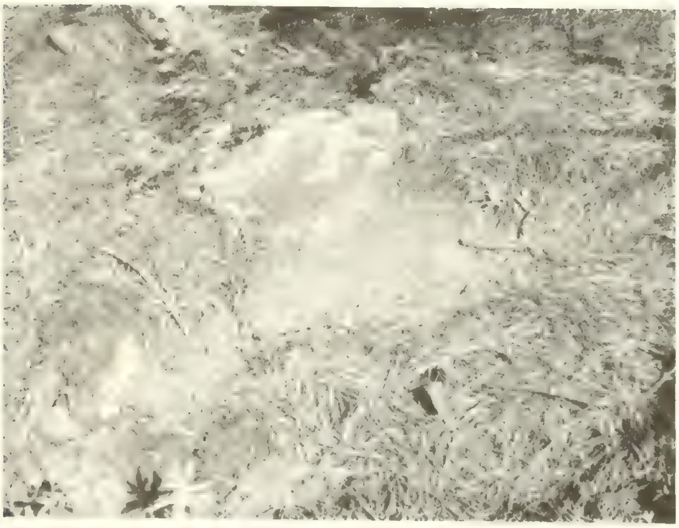

Figure 2.--Water apparently flowed through this thick forest floor without disturbance until it was diverted or ponded by stones. When this happened, the litter floated and moved downslope (right to left), leaving a small spot of bare mineral soil. Many such spots could be seen on some slopes.

Antecedent Rainfall and Moisture Conditions

Precipitation had not been excessive, January through May, at any of the continuous measuring stations in the Hills. Distributions by months were near average, and totals for representative stations varied from slightly below to slightly above average (table 1). Temperatures had not been extreme. In short, there were no apparent clues leading up to the extreme storm and flood event of June 9-10. Apparently it was a random event, neither preceded nor followed by distinctive extremes.

On the other hand, the topography and location of the Black Hills in relation to the nature and movement of major weather systems would appear to make the area a more likely prospect for development of the kind of storm that occurred on June 9 than most parts of the continental United States. In other words, atypical behavior of meteorological elements, such as the low-velocity winds aloft which occurred over the Hills on June 9, might, in combination with other factors, be expected to evoke a more violent reaction than in other areas.

By June 9 evapotranspiration usually exceeds precipitation input, and soil moisture storage deficit is increasing. Before the end of May, soon after the start of the growing season, streamflow is usually declining while precipitation increases to maximum in June. Precipitation and flow were, in general, following the usual patterns up to June of 1972. Some stations received practically no precipitation in the week preceding June 9, while others (Pactola Dam in table 1) received relatively large amounts as late as June 4.

Flooding occurred from watersheds in all of the major geologic types in the Hills. Though the nature of flooding was clearly influenced by soils and geology, precipitation amounts and intensities were the primary factor. Type of vegetation and biomass per unit area (relative evapotranspiration) no doubt also had less effect than they would have had later in the growing season. Effects of differential evapotranspiration would not yet have accumulated to as great a degree.

Flood Peaks

Peak unit area discharges (as computed from USGS measurements)[2] do not coincide with ranking of mean area rainfall (table 2). The highest mean area rainfall (of the watersheds computed) occurred on Este Creek, a 6-square-mile tributary of Boxelder Creek. Parent material is primarily metamorphic. Though the unit area discharge is no doubt among record highs for watersheds of comparable size in the entire United States, it was not the highest measured.

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[2] *Data obtained from Rapid City Subdistrict Office, Water Resources Division, U. S. Geological Survey.*

Table 1.--Precipitation at selected stations (from January 1, 1972), prior to the June 9, 1972 Black Hills storm and flood, in comparison with average

Time period	Sturgis No. 2	Experiment Forest Arboretum	Pactola Dam	Rapid City
	- - - - - - - -	- - - - - - - - Inches	- - - - - - - -	- - - - - - - -
January	1.37	0.96	0.21	0.34
February	1.01	.76	.31	.41
March	1.32	1.07	.67	.52
April	4.11	2.62	2.24	2.45
May	5.48	4.24	2.89	3.19
June 1-8	.13	.93	3.91	.34
Sum through May 1972	13.29	9.65	6.32	6.91
Long-term average through May	14.56	11.12	8.14	6.48
Sum through June 8, 1972	13.42	10.58	10.23	7.25

Peak unit area discharge was practically the same from Victoria Creek (tributary to Rapid Creek) as from Este Creek, but the recurrence interval is much greater, although parent material is also metamorphic and computed mean rainfall was considerably less. Reasons are not apparent, although they may be related to the method used by U.S. Geological Survey (USGS) to calculate estimated 50-year discharge (Patterson 1966). The recurrence intervals in table 2 are expressed in terms of multiples of the 50-year peak discharge as computed by USGS.

The highest per-unit-area discharge, and by far the greatest recurrence interval, occurred from Cleghorn Canyon (Wild Irishman Creek), tributary to Rapid Creek at the west edge of Rapid City (table 2). Area average rainfall was not the highest, though as much as 13 inches reportedly fell in the middle to lower reaches of the watershed. One distinctively different physical characteristic of the watershed (compared with others listed) is that it is almost entirely on sedimentary formations, Deadwood sandstone and Pahasapa limestone in upper reaches to sandstones with interbedded limestones and red shales of the Minnelusa formation at the junction with Rapid Creek. Also, the upper portion of the watershed burned in September 1936 (the 760-acre Johnston fire).

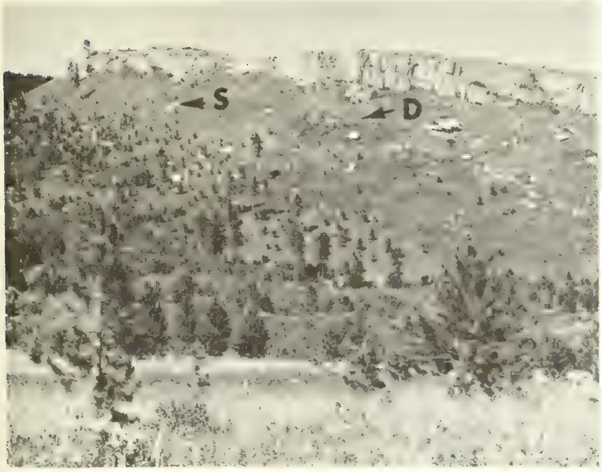
Much of this old burn has not come back to pine (figs. 3, 4, 5). Aspen and birch are now abundant on the more moist slopes and in stream bottoms. Most of the remaining area is well vegetated with herbaceous species and shrubs. There is considerable private land and residential development in the lower reaches (Cleghorn Canyon). There was evidence of runoff from all types of areas, but slope damage was minimal, even on the kind of steep south-facing slope shown in figure 3. This is one of the slopes bared in the 1936 fire. Figure 6 is a closeup of the left portion of this same slope. Pine reproduction is sparse, but the site is well stabilized by herbaceous vegetation. One landslide, visible in figure 3 and shown closeup in figure 7, occurred on this slope. The slide was not large, about 32-35 feet long and about half as wide, and apparently resulted from a combination of water concentration from up-

Table 2.--Peak discharge and area average precipitation of selected Black Hills watersheds, flood of June 9, 1972 (in order of area average rainfall as computed by Rocky Mountain Forest and Range Experiment Station)

Drainage	Peak discharge		Recurrence interval[2]	Area average rainfall	Area
	C.f.s.[1]	C.s.m.		Inches	Sq.Mi.
Este Creek (near Nemo)	6,620	1,078	6.0	10.69	6.14
Deer Creek at campground 8 miles west of Rapid City	3,530	825	23	9.96	4.28
Gordon Gulch (near Sheridan Lake)	(3)			9.42	[4]3.15
Horse Creek (at Sheridan Lake)	1,830	181	6.7	9.09	10.1
Deadman Creek (at Sturgis)	4,740	797	4.5	8.78	5.95
Battle Creek (at Keystone)	10,800	794	8.8	8.34	13.6
Little Elk Creek (at Elk Creek)	(3)			8.04	[4]19.7
Cleghorn Canyon (Wild Irishman Creek)	12,600	1,813	61	7.87	6.95
Prairie Creek (at Rapid Creek)	(3)			7.21	14.0
Grizzly Bear Creek (near Keystone)	6,230	676	6.4	7.11	9.22
Victoria Creek	6,860	1,022	35	7.10	12.8
Iron Creek	(3)			6.68	16.3

[1] From USGS measurement by slope-area method.
[2] Multiple of 50-year peak discharge as computed by USGS.
[3] Not measured by USGS but flooding severe.
[4] Measurement from Rocky Mountain Forest and Range Experiment Station.

Figure 3.--A south-facing slope in the upper reaches of Wild Irishman Creek (Cleghorn Canyon). The area burned over 36 years ago, and much of it has not come back to pine forest. The rock outcrop is Pahasapa limestone, with darker Deadwood sandstone outcrop (D) about 1/4 of the way downslope. Vegetation is well established and the soils are stable. S indicates slide area closeup in figure 7.



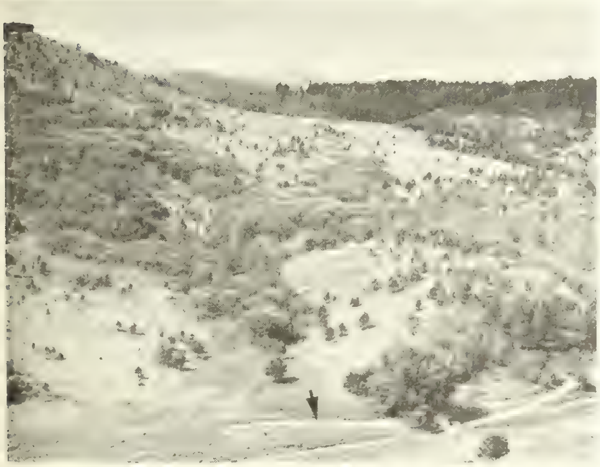
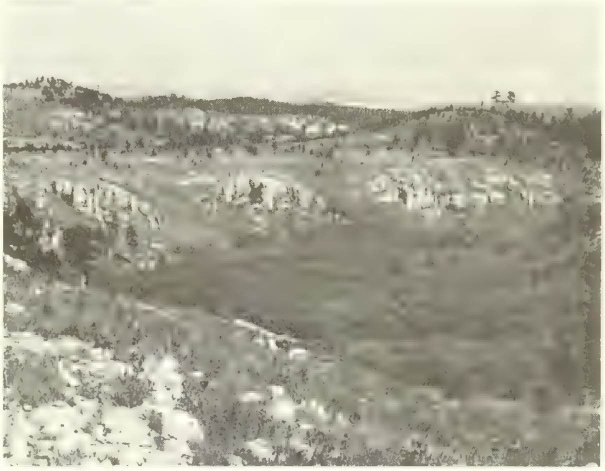


Figure 4.--Looking back southwest from high on the slope in figure 3. One of the main tributary channels of Wild Irishman shows in the lower portion of the photo, and flood-deposited material is visible (arrow), together with an old road.

Figure 5.--Valley bottoms in the old 1936 Johnston Fire (760 acres) were invaded by aspen and birch. These species also invaded on the more moist north-facing slopes, as shown in figure 4. This view is from the top of the ridge in figure 3, looking almost directly east toward Rapid City in the far background.



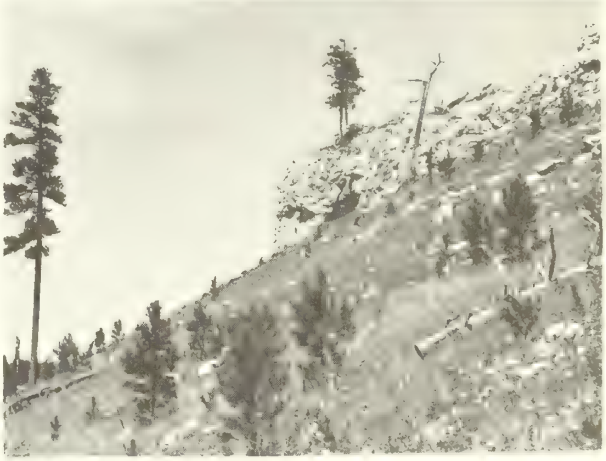


Figure 6.--Looking mostly west (left) across the left portion of the slope in figure 3. Vegetation is a well-established mixture of grasses and forbs. Soils are stable for the most part.

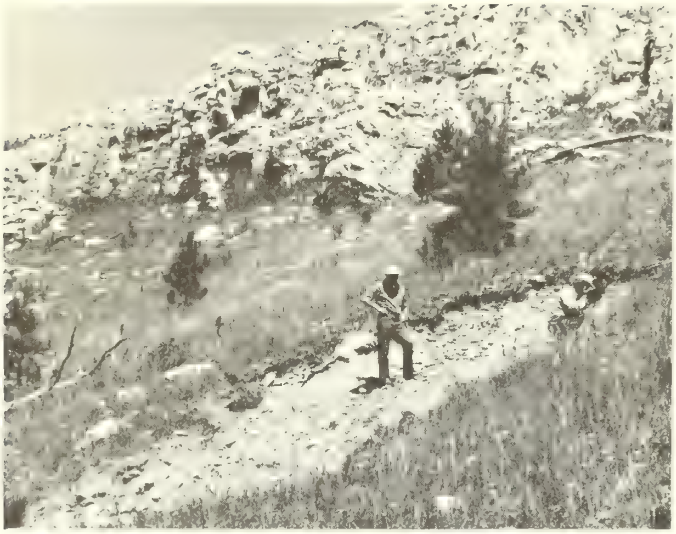


Figure 7.--To the right of the area in figure 6 is this small flow slide about 30 to 35 feet long and about half as wide. It was the only visible area on the entire slope where any appreciable amount of soil was displaced.

slope and liquefaction of shallow, stony soil on bedrock (possibly upper Deadwood sandstone) which was near but did not intersect the slope plane. The flow slide material moved all the way downslope to the main channel, and was no doubt the source of some of the water-deposited material in the lower portion of figure 4. Vegetation was not stripped from the slope in the slide path, however.

Some additional channel cutting and deposition, associated mainly with old roads, was evident in upper reaches. Practically all of that debris was intercepted and filtered out by shrub and herbaceous vegetation in open meadow areas such as that shown in figure 4. Severe channel cutting and erosion became increasingly evident further downstream in the narrower, more constricted lower canyon.

Much debris (including tree branches, limbs, and roots) lodged on the upstream side of trees (fig. 8). Several such deposits were examined closely. None of the debris originated as logging slash, as was at first thought. No axe or saw cuts were visible. The debris obviously came from trees close enough to the channel that record high flow literally tore them out and stripped them of limbs and foliage. Ring counts of some of the trees deposited in debris piles indicate they were 80-85 years old. In other words not since at least 1890 had any combination of storms, fire, timber stand conditions, grazing, or other land use produced such large floods. In Boxelder, and undoubtedly in other drainages, trees were downed that had been in place more than 100 years—long before settlement by white man.

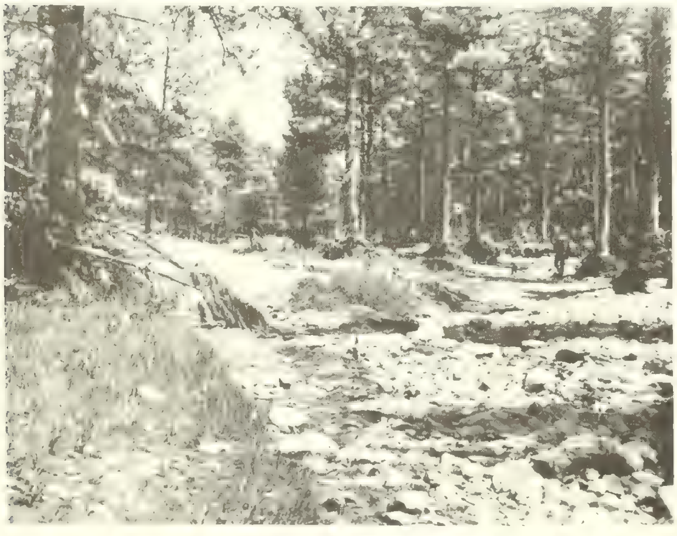


Figure 8.--Woods debris 8 to 10 feet high against the upstream side of trees in Wild Irishman (Cleghorn Canyon), downstream from the areas shown in figure 3 to 7. Here the channel has broadened and there is less gradient, but it steepens and narrows again before joining Rapid Creek at the west edge of Rapid City.

This conclusive evidence negates serious speculation that this rare flood event may indicate general environmental degradation. Severity of consequences of the flooding, though none the less tragic, were in direct proportion to man's encroachment on stream channels and floodways. Also, man-origin debris no doubt caused more environmental deterioration or damage than any **a priori** upstream land use or management. Similar consequences, though less spectacular and without the great loss of life, occurred in 1962 and earlier.

Another watershed of particular interest is Grizzly Bear Creek, which drains from a research natural Area on the Precambrian granite of the Harney Range (fig. 9). This area has had little disturbance of any kind in many years. Yet the stream flooded inside as well as outside the boundary of the Natural Area, enough to drastically erode and alter some channel sections. Litter piles and associated upslope bare spots again attested to the production of significant surface runoff from a microtopography that would not ordinarily be noticed. There is evidence, however, that watersheds in this general area have low storage capacity due to coarse-textured parent material, and an obvious history of flooding, even during much lesser storms.

A large proportion of the most heavily flooded watersheds was in areas of metamorphic parent material of the general type shown in figure 10. Material of this type characteristically breaks down to loamy soils, often quite stony. The kind of erosion shown in figure 11 is typical of what happened to cut slopes in residual soil. Fines were washed out, leaving stones protruding. Slumping of steep road cuts was not uncommon in this kind of situation.

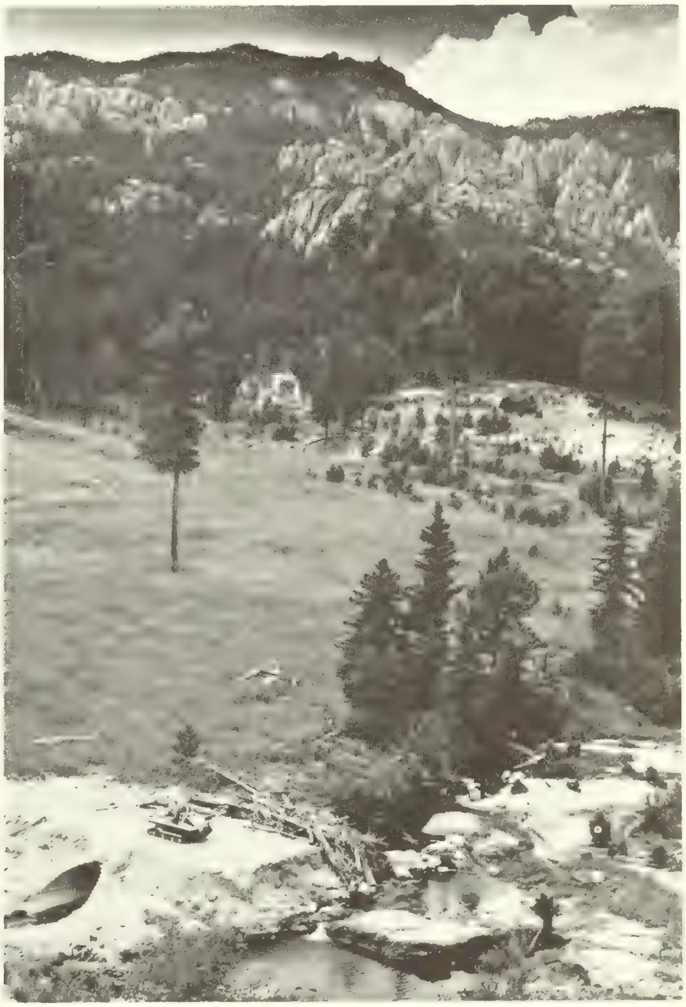


Figure 9.--Channels eroded severely, even in areas that have received little use in many years. Shown here is Grizzly Bear Creek, draining out of the Pine Creek Natural Area in the Harney Range. Parent rock is granite, which here weathers to a coarse-textured shallow soil with low storage capacity.

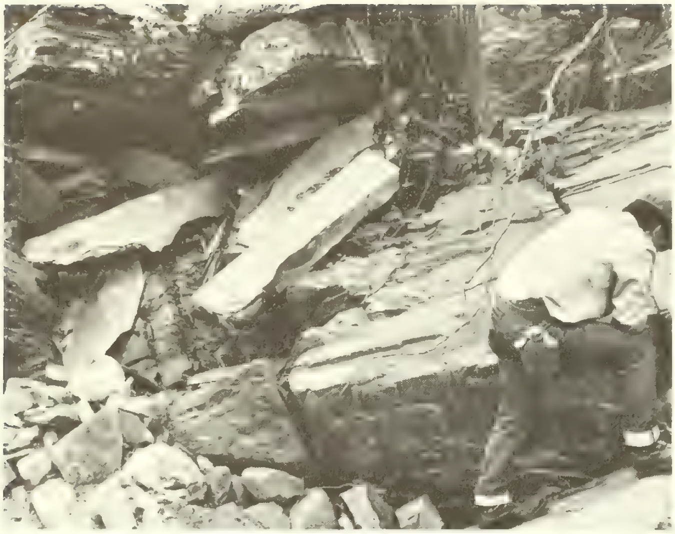


Figure 10.--Characteristic metamorphic parent material in part of storm area that received some of the heaviest rainfall. Flooding from a drainage no more than 1 mile long caused this channel damage, which was on the outside of a turn.

Experimental Watershed Response

The best quality overall precipitation and flow records that we know of are from the three Sturgis Experimental Watersheds — 217, 89, 190 acres — in the northeastern Black Hills. These records are used to illustrate flow timing and distribution in relation to precipitation. The total volumes of flood flow cannot be determined, however, because of debris accumulations which practically covered the stations during recession (figs. 12, 13, 14). Accumulation apparently started at about the same time as the peaks occurred or soon after. The stations were not structurally damaged, however, despite the force of debris and peak flow about twice the design discharges computed for 1.87 inches of rain in 1 hour (table 3). Hence, the flume hydrographs are available from start of rise to the approximate peaks at all three stations.

Table 3.--Rainfall by individual gages at the Sturgis Experimental Watersheds, June 9, 1972

Gage	Total precipitation	Maximum 6-hour precipitation	
	Inches	Inches	Hours
A-1	8.68		
A-2	11.64	10.47	1500-2100
A-3	10.49		
A-4	9.57		
A-5	8.86	7.76	1450-2050
A-6	10.01		
A-7	10.96	[1]9.72	([1])

[1] By proportion, from gages A-2 and A-5; distribution record lost, only total depth available.

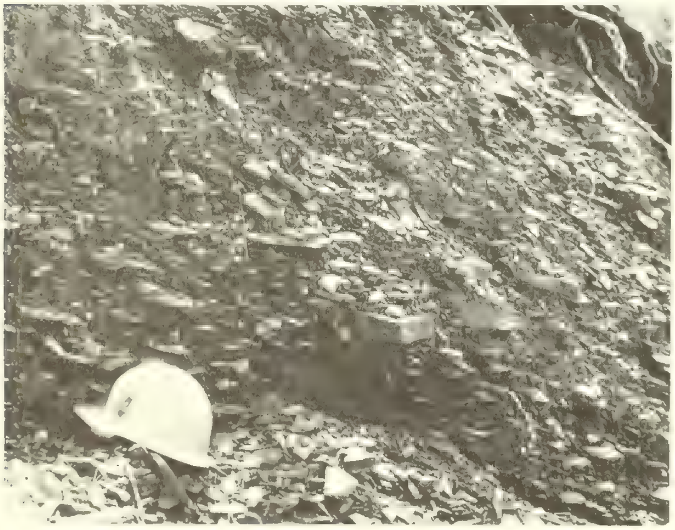
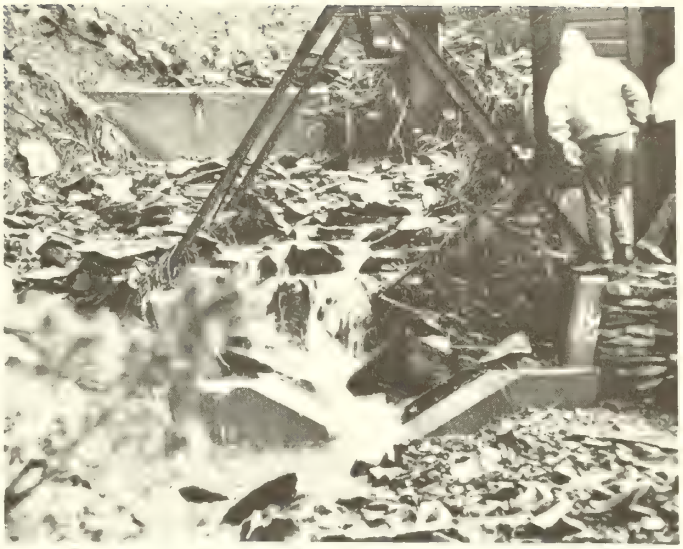
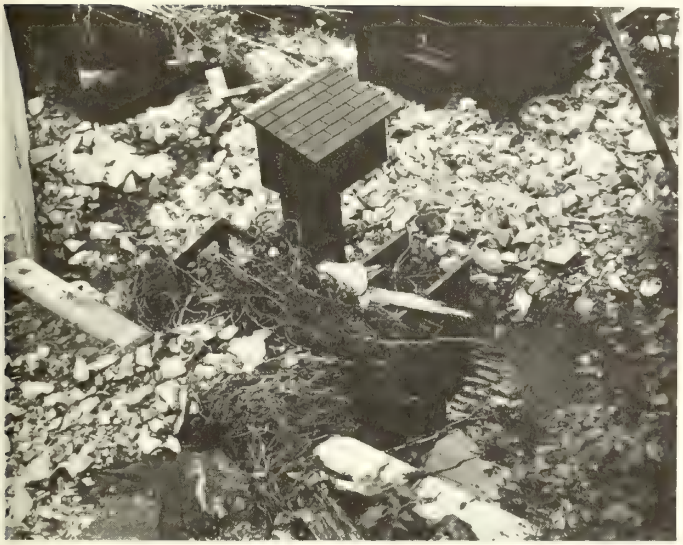


Figure 11.--An old road cut through residual soil, metamorphic parent material, after the June 9 flood. Fines were washed out. Platy rock was then either left protruding or it fell out and into an accumulation at the base of the slope. This sort of thing did not happen on newer back-sloped roads.

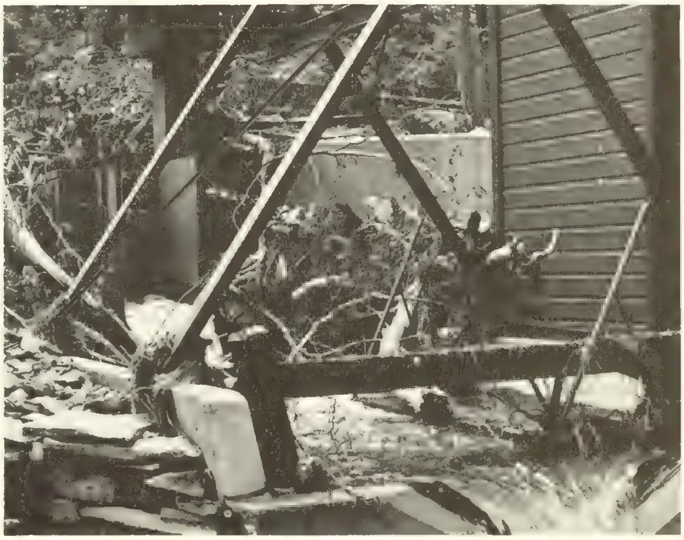
Figure 12.--Watershed 1 → gaging station nearly covered over with stone and other debris, and completely inoperable after the June 9 flood.





← Figure 13.--Watershed 2 gaging station after June 9 flood. San Dimas flume and channel is full of stone and other debris at left (upstream from headwall). Weir pond is completely obscured. Station was intact but inoperable.

Figure 14.--Watershed 3 gaging → station after June 9 flood. The station continued in operation despite the debris pileup. Nearly 400 man-hours of labor were required to return all three gaging stations to temporary standby operation.



Watershed 3 (WS3) flume functioned through the entire storm, but flow figures are not reliable after debris started to pile up following the peak, and because some water crossed over from WS2 to WS3 just upstream from the gaging stations. At least up to the peak the WS3 record is judged the best.

Rainfall started at almost precisely 1450 (m.s.t.) in all three recording gages at the watershed. The main streams started to rise almost immediately in all three watersheds, but the rise was relatively slow until between 1600 and 1700, when the heaviest sustained rainfall began. Flow then accelerated very rapidly.

Time at which flow started to accelerate most rapidly in WS3 coincided almost precisely with the start of a second period of high-intensity rain (at 1630) at rain gage A-2 in the upper reaches of the watershed. Over 3 inches of rain had already fallen — apparently enough to fill available soil storage capacity and cause the flow to respond almost immediately to additional high-intensity rain. From 1630 to 1820 the discharge increased steadily from 6 to 80 c.f.s. Maximum 1-hour rainfall occurred in this time interval — 3.25 inches at rain gage A-2 (1630 to 1730) in the head of WS2, and 2.12 inches at rain gage A-5 (1645 to 1745) on the east boundary of WS1.

The watersheds behaved about as would be expected. WS2 apparently received most rainfall (fig. 15), and produced the highest unit area peak runoff (table 4). WS3 received second largest amount of rain, produced the second highest unit area peak runoff, and the second largest total area depth of runoff to the hydrograph peak. WS1, the most easterly of the watersheds, received the least rain, produced the lowest unit area peak flow, and the least depth to peak.

Maximum peaks (fig. 16) were less clearly recorded in WS1 and WS2 than in WS3. Nevertheless the peaks, as well as amounts already presented, are reasonable. WS1 hydrograph did not start maximum acceleration until about 1 hour after WS3, which is not surprising considering the fact that by the time of peak in WS3, 2 inches more rain had fallen there than in WS1.

Reasons for the two recorded peaks at WS1 are not clearly apparent. It may be that landslides (several occurred in WS1 and WS2, fig. 17) temporarily blocked flow. The debris dams then washed out, probably releasing enough surge of water to cause another peak at the gaging station. Several such slides may also have been one reason why the hydrograph in WS2 lagged behind both WS1 and WS3, particularly if the slides occurred at about the same time. Response times were opposite what might have been expected considering the fact that, in calculating design discharges, the concentration times were 12.6, 9.0, and 16.2 minutes for WS1, WS2, and WS3, respectively.

The slides themselves are of interest. Most of the ones adjacent to stream channels appear

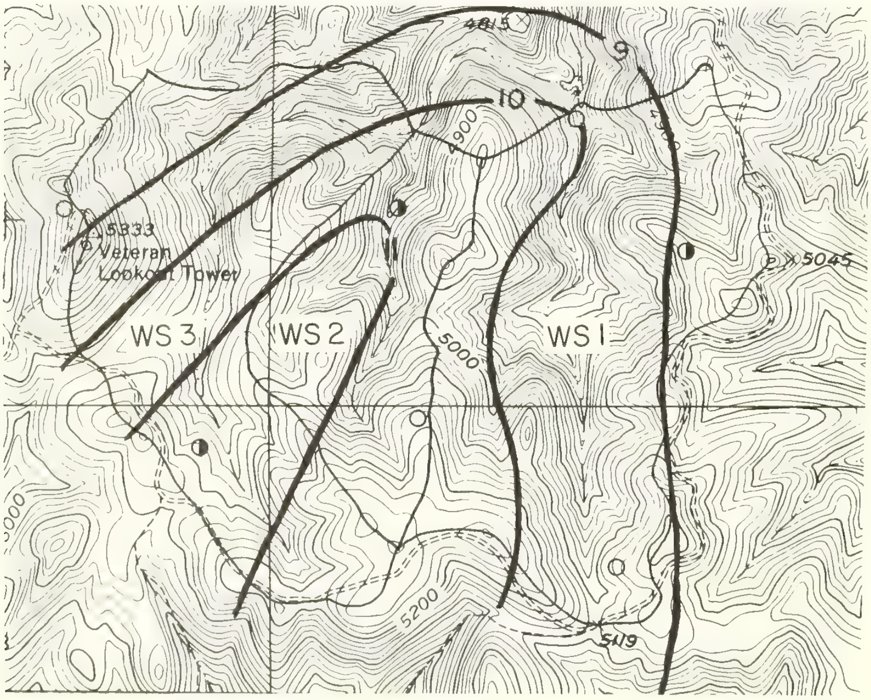


Figure 15.--Isohyetal map of the June 9, 1972 flood-producing storm on the Sturgis Experimental Watersheds: Left, watershed 3; Center, watershed 2; Right (east) watershed 1.

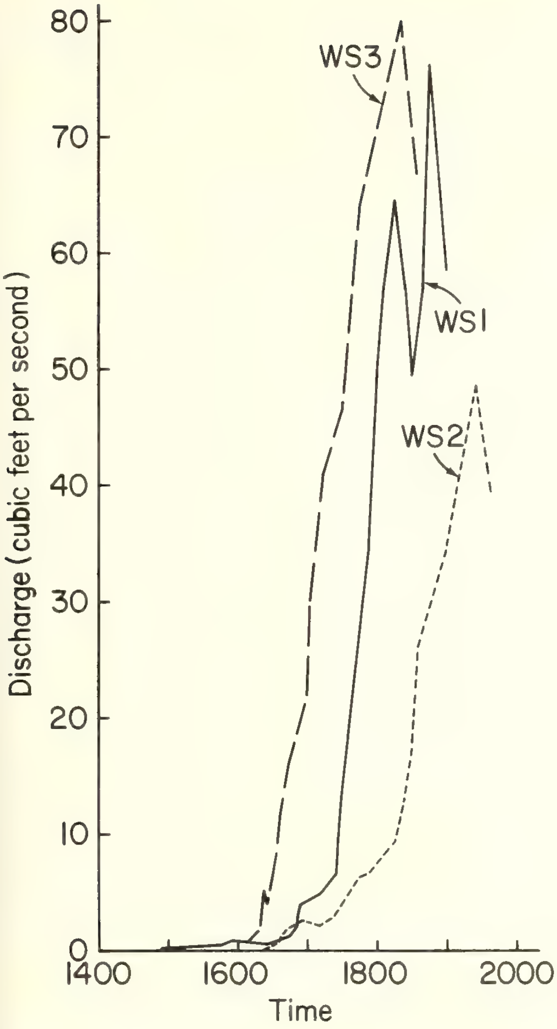


Figure 16.--June 9, 1972 storm flow hydrographs to about time of peaks. Debris deposits caused loss of the remainder of the hydrographs.

Table 4.--Area rainfall and storm discharge, Sturgis Experimental Watersheds, June 9-10, 1972

Item	Watersheds 1	2	3
Average precipitation (inches):			
Thiessen	9.28	10.83	10.47
Isohyetal	9.59	10.86	10.16
Recorded hydrograph:			
Approximate start of rise (m.s.t.)	1450	1514	1450
Time of peak (m.s.t.)	1840	1930	1832
Time to peak (hrs.& min.)	3:50	4:16	3:42
Discharge:			
Peak (c.f.s.)	76	49	80
Peak (c.s.m.)	225	349	269
Depth to peak (area inches)	.28	.47	.44
Computed 25-year design discharge (c.f.s.)	45	20	37
1972 multiple of 25-year	1.7	2.4	2.2

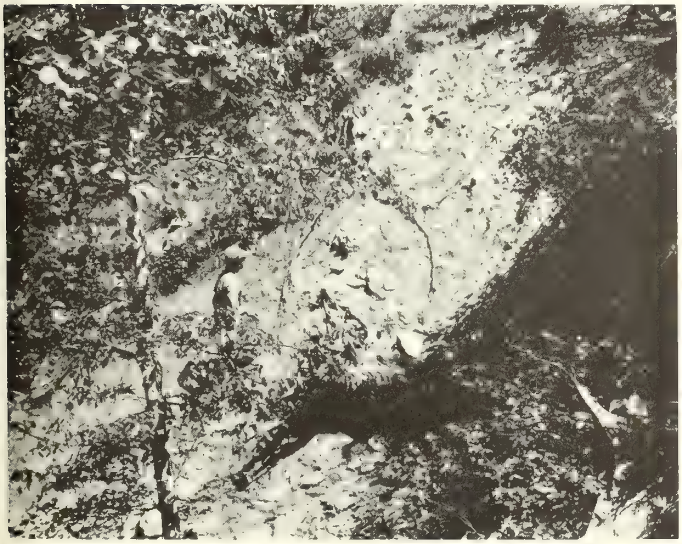


Figure 17.--Flow slide from channel bank in Sturgis WS1. A number of such slides blocked channels until enough water accumulated to overtop and cut through the debris. Debris in foreground is on near side of channel, which extends from right to left where man is standing.

to have occurred as the result of liquefaction of the toe of a slope by water flowing more than channel deep. Most of the slides were of the flow type (versus the rotary type). None we have seen within the watersheds were large, but there were enough of them to no doubt contribute a substantial portion of the bedload that choked the gaging stations and deposited in water supply reservoirs downstream. Several larger flow slides occurred on talus slopes along the main access road, which appear to have started as moisture accumulated to low tension along a road cut. Debris flow appears to have started at the cut face and progressed upslope —to near the ridge crest in several cases. Several such slides blocked the main access road.

Timber was harvested from WS3 in 1970 and 1971 (132 acres, 73 percent of total area). Some temporary haul road was constructed, but most was well up on a slope and away from main channels. Harvesting activity does not appear to have accelerated either the runoff or channel erosion. Haul roads and skid trails suffered minor damage, and little, if any debris reached major channels.

Summary and Conclusions

An unusual combination of atmospheric conditions triggered thunderstorms of unprecedented depth and duration from midafternoon on June 9, 1972 to early morning June 10, along the east slope of the Black Hills. Flash floods resulted in great loss of life, particularly in heavily populated areas along Rapid Creek, and property damages estimated at more than $100 million in Rapid City alone.

The storm was of such magnitude that recurrence interval is more than ordinarily problematical. Six-hour amounts ranged as high as 12 inches. Recurrence is variously estimated as four times the amount expected once in 100 years on the average (U.S. Department of Commerce 1972) to once in several thousand years (Thompson 1972). Flood flow peaks ranged as high as 62 times the once in - 50 - year discharge as estimated by the United States Geological Survey.

Portions of all of the major geologic types of the Black Hills were present in the torrent area. All major land uses ranging from commercial forest and agriculture, to intensive urban development were also present. All types of areas produced runoff of unprecedented proportions. Some areas yielded channel flow where long-time residents never before saw surface flow. The obvious conclusion is that runoff was produced regardless of how good the hydrologic condition. For example, surface runoff occurred under forest with thick protective litter, and concentrated in drainageways of microtopography that would not ordinarily be seen. The event was apparently so rare that the flash flooding cannot be taken as indication of general environmental degradation.

The land, regardless of condition or use, obviously could not receive and transmit the amount of rain that fell without changes in the face of the land itself. Part of these changes were the inevitable result of natural processes. In this framework, classification as "damage" is problematical.

On the other hand, damage was unprecedented where there was loss of life and the works of man were involved. A lesson to be relearned from this disaster is that encroachment on natural flow channels will inevitably result in damaging floods — some time. Flood damage in 1962 and earlier was also greatly compounded by man-origin debris, and, although cause and effect were both well documented, they were soon forgotten. All the major drainages in this 1972 flood have some known history of flooding, and they will flood again — some time. Extent of future damages will depend on sophistication of engineering works designed to **control and meter flood flows**, thus permitting continued occupancy of flood plain, or it will be necessary to **withdraw** from the most flood-susceptible areas. The final action, if man does not again forget too soon, will no doubt be a combination of the two.

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Rains of 12 inches or more in 6 hours fell on the east slopes of the Black Hills the night of June 9, 1972. Resulting flash floods exacted a disastrous toll in human life and property. Rainfall and discharge so greatly exceeded previous records that recurrence intervals have been presented in terms of multiples of the estimated 50- or 100-year event. Quick runoff was produced in the heaviest rainfall areas regardless of hydrologic condition. Flood sources included all major geologic and soil types and practically all land uses in the Black Hills. The highest measured peak runoff per unit area came from a 7-square-mile drainage, all on sedimentary formations, the upper portion of which burned over in 1936, but which is now well vegetated, apparently stable, and in good hydrologic condition. Greatest damage occurred where man-origin debris piled up against bridges, highways, homes, and other improvements.

Keywords: Floods, watershed management, hydrologic data, flash floods, storm runoff, record rainfall.

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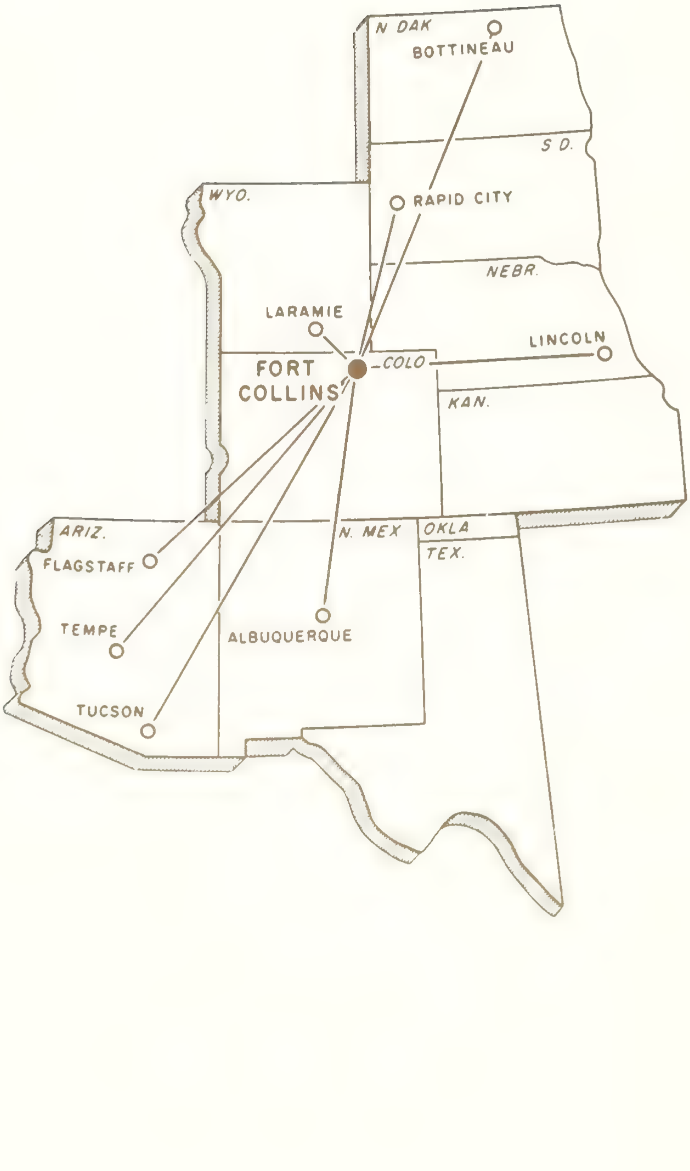
Orr, Howard K.
1973. The Black Hills (South Dakota) Flood of June 1972: Impacts and Implications. USDA For. Serv. Gen. Tech. Rep. RM-2, 12 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Rains of 12 inches or more in 6 hours fell on the east slopes of the Black Hills the night of June 9, 1972. Resulting flash floods exacted a disastrous toll in human life and property. Rainfall and discharge so greatly exceeded previous records that recurrence intervals have been presented in terms of multiples of the estimated 50- or 100-year event. Quick runoff was produced in the heaviest rainfall areas regardless of hydrologic condition. Flood sources included all major geologic and soil types and practically all land uses in the Black Hills. The highest measured peak runoff per unit area came from a 7-square-mile drainage, all on sedimentary formations, the upper portion of which burned over in 1936, but which is now well vegetated, apparently stable, and in good hydrologic condition. Greatest damage occurred where man-origin debris piled up against bridges, highways, homes, and other improvements.

Keywords: Floods, watershed management, hydrologic data, flash floods, storm runoff, record rainfall.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ABSTRACT

Seven technical presentations, made in connection with the USDA Forest Service National Avalanche Training Program, discuss acoustic signals emitted by snow under stress, aspects of snow slab mechanics, use of explosives, and problems of avalanche dynamics.

Oxford: 384.1:111.784. **Keywords:** Avalanches, snow management.

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General Technical Report RM-3

September 1973

ADVANCES IN NORTH AMERICAN AVALANCHE TECHNOLOGY: 1972 SYMPOSIUM

Compiled by

R. I. Perla

Alpine Snow and Avalanche Project
Rocky Mountain Forest and Range Experiment Station[1]

Technical presentations made in connection with the
USDA Forest Service National Avalanche Training
Program, Reno, Nevada, November 16-17, 1972

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[1] *Central headquarters is maintained in cooperation with Colorado State University, Fort Collins.*

ADVANCES IN NORTH AMERICAN AVALANCHE TECHNOLOGY: 1972 SYMPOSIUM

PREFACE

As part of its National Avalanche Training Program, the USDA Forest Service hosted a symposium at Reno, Nevada, on November 16 and 17, 1972. The symposium, arranged by R. I. Perla and R. H. Spray, was chaired by E. R. LaChapelle. Seven of the technical presentations are published herein.

The opening contribution by W. St. Lawrence and C. Bradley reports on acoustic signals emitted by snow under stress. One exciting breakthrough is mentioned—the discovery of the Kaiser acoustic effect in snow. St. Lawrence and Bradley envision that acoustic emission phenomena, including the Kaiser effect, may have important applications for testing the structural integrity of avalanche slopes.

The next four contributions discuss various aspects of snow slab mechanics. This research is motivated by needs of the ski industry to control the slab avalanche problem. Reading these papers, one may conclude that snow slab mechanics is a young, wide-open subject. There is still much speculation on the release mechanisms of slab avalanches, and the stage is set for some convincing experiments.

Since the basic mechanics of slab release are unknown, many uncertainties exist about how to artificially release slab avalanches with explosives. The paper by M. Mellor is a bold start in explaining how explosives can be used rationally and systematically in avalanche technology.

Research effort in the United States has centered around slab-stability investigations; Canadian research, however, has looked into the problems of avalanche dynamics. In a brief, significant report, P.A. Schaerer presents a very practical way of computing impact pressure of moving avalanches.

R. I. Perla, Compiler

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ULTRASONIC EMISSIONS IN SNOW

William St. Lawrence and Charles Bradley

ABSTRACT

Burst type acoustic signals have been monitored in snow subjected to various load and deformation histories over a wide range of frequencies. The pattern of the acoustic response is closely related to the particular load or deformation history applied. Examination of the emission pattern suggests a description of the deformation of snow in terms of a structural mechanism. The results of a number of experiments are given and interpreted in terms of their acoustic response.

Also presented is a discussion of the possible application of the acoustic emission technique for making *in situ* measurements of the state of stress in an active snow slope.

Introduction

A number of different types of acoustic signals which emanate from snow subjected to mechanical loadings have been detected. These signals can be broadly classified into two groups: audible and subaudible. In terms of audible signals we can cite such examples as the squeaking which can often be heard when walking on snow on a cold day, or the sharp report which accompanies a rapidly propagating crack in the tensile region of a snow slope. Less familiar examples of audible sounds that can be detected in snow are the sound of a collapsing snowpack, and the sound of one layer of snow slipping over an adjacent layer.

The second category, subaudible noise, can be subdivided into frequency related classifications. In one instance the sound is in the audible spectrum, but is of such low intensity that it cannot be detected by the unaided ear. To date we have detected this type of signal only in snow samples subjected to deformation rates which induce a brittle response in the snow. The second type of noise is ultrasonic. This type of acoustic emission has been monitored in snow over a wide range of loadings. It is this kind of emission that will be dealt with in this paper.

Emission Characteristics and Possible Sources

To investigate the nature of ultrasonic emissions in snow, consideration must be given to the possible source of the acoustic event, and to the system used for detecting it. Consideration of the acoustic emission monitoring system, and in particular the transducer, is important since information obtained in terms of frequency content, amplitude, and duration of an acoustic event in general reflect system characteristics. The source disturbances probably bear little resemblance to the signal that is recorded. In defining ultrasonic emissions we are indicating that the transducer used is most sensitive to excitation in the ultrasonic region of the frequency spectrum.

Since the energy release associated with a burst emission is small (an estimate in the neighborhood of 10^{-13} Joules has been suggested by Liptai et al. 1971), it is customary to monitor the transducer used to detect the acoustic signal in the vicinity of one of its resonance peaks. This method makes it possible to detect small amplitude signals, but provides little information about the form of the exciting signal. Using this technique limits the information obtained to establishing a transient disturbance has taken place, and that the disturbance has sufficient energy in the region of the transducer resonant frequency to excite the transducer to resonance. A definite advantage in working in the ultrasonic region of the frequency spectrum is that for frequencies above 30 KHz interference from extraneous noise is minimal.

As indicated above, it is difficult to describe in any detail or with any precision the form of the acoustic emission as it originates. The fact that acoustic signals are detected in snow indicates that when snow is subjected to mechanical loadings, a nonconservative energy conversion takes place, with part of this energy being dissipated in the form of noise.

It is probably correct to assume that acoustic energy represents only a small portion of the total energy dissipated. From oscilloscope and magnetic tape records we can establish that the emission of sound from snow occurs in bursts of noise rather than continuously. These bursts take place at intermittent intervals depending on the particular loading applied.

To identify the sources of acoustic emissions in snow we will rely on observations that have been made of the structural changes that take place in snow during the deformation process. From these observations we can tentatively identify possible emission sources. For deformation rates which produce a brittle response in the snow, Kinosita (1967) observes that failure is characterized by the breaking of bonds between ice crystals composing the snow matrix. For this type of deformation we detect both ultrasonic and audio signals emanating from the snow. Since Kinosita indicates that intercrystalline fracture is the only means by which snow deforms at high rates we are probably correct in assuming that for these rates some form of intergranular movement generates the acoustic signal observed.

For snow that is deformed at rates which produce a plastic response, acoustic emissions may be due to a number of different mechanisms. Observations reported by Wakahama (1967) on the compression of snow at slow rates indicate that the structural changes which take place in the snow matrix are basal glide, slip at grain boundaries and separation of ice grains. It appears plausible that accoustic emissions can originate from the formation of slip planes in the ice grains and also from the separation of ice grains. In the case of the formation of the slip plane this takes place at a rapid rate in the ice grain. A number of these slip planes forming simultaneously in the ice crystals comprising the snow matrix might produce an acoustic signal at a level that can be detected. If the separation of ice grains takes place in a rapid manner this may also represent an acoustic source. In the case of slipping at grain boundaries it would appear that this kind of process would not generate sufficient power to produce a detectable acoustic signal. Wakahama also reports that in addition to these primary mechanisms grain fracture, void formation, and grain boundary migrations are also observed. In considering these mechanisms as possible acoustic source it is probable that grain fracture and the formation of voids within grains could generate transien acoustic signals. A number of experiments are now being planned which will attempt to look at each of the above mechanisms as possible emission sources; one that is presently being considered on a theoretical basis is the form of the stress wave which might emanate from these mechanisms.

Acoustic Emission Monitoring System

The experimental system which is used to monitor and record acoustic emissions in snow, in the laboratory, is shown schematically in figure 1. This system is typical of many acoustic emission systems presently employed for work in materials research. Since the basic acoustic emission system is well described in the literature, the reader is referred to papers by Tatro (1971) and Dunegan and Harris (1969) for complete details. It is worth commenting on a special modification that is necessary when working with snow.

Since snow is a soft material, mounting the transducer to the snow poses two special problems. Care must be taken so that spurious stress fields are not set up by having the transducer come in direct contact with the snow. Also, many tests are conducted at relatively high rates and to larg deformations, so that it is possible to generate pseudo-emissions caused by the relative motion between the specimen and the transducer. Both of these problems are solved by applying a thick coating of silicon grease to the transducer so that it is not in direct contact with the snow sample.

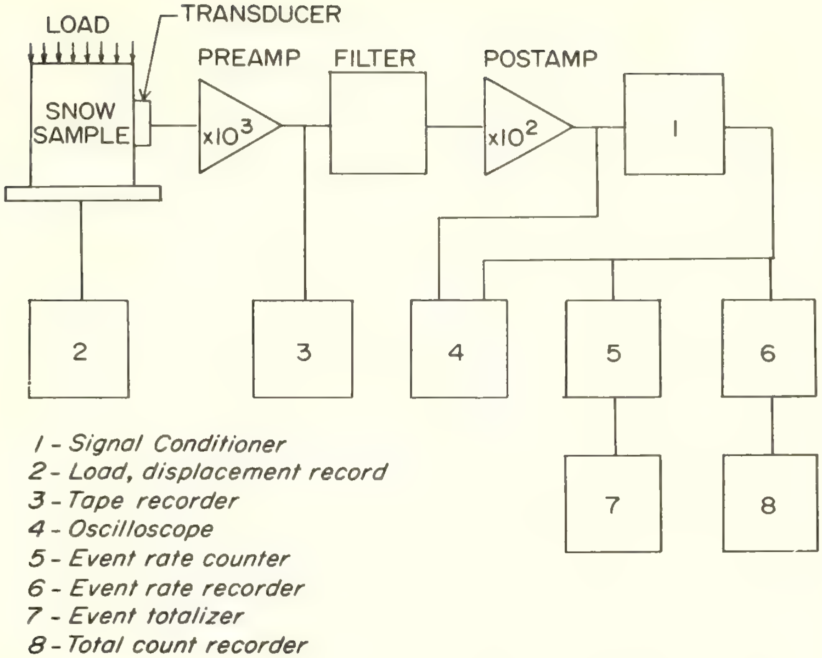
The system used in our present experiments records only the rate at which emissions occur and the total number of emissions.

Experimental Results

In order to establish baseline data on acoustic emissions in snow, we conducted a series of experiments in which a number of load and deformations were applied. These experiments consisted of constant rate tests in tension, compression, and torsion and creep tests in tension and compression. The snow used in these experiments can best be classified as IIB2, using the classification system of Sommerfeld and LaChapelle (1970).

Figure 2 depicts a typical emission response curve (rate of emission vs. time) for a sample of snow subjected to a constant rate of deformation. The stress time curve for this test is also shown. The snow in this test was deformed at a constant angular rate of 2.2° per minute (0.12° per minute per centimeter of length.) for 20 minutes and allowed to relax for 10 minutes. At the end of the 10-minute relaxation period, the specimen was then reloaded at the same rate. The results obtained when the specimen was reloaded are also shown. The stress response curve is for the shear stress calculated at the specimens outer radius. The acoustic response depicted here is typical of the results obtained for snow subject to constant deformation rates, with variations

Figure 1. Acoustic emission monitoring system for snow.



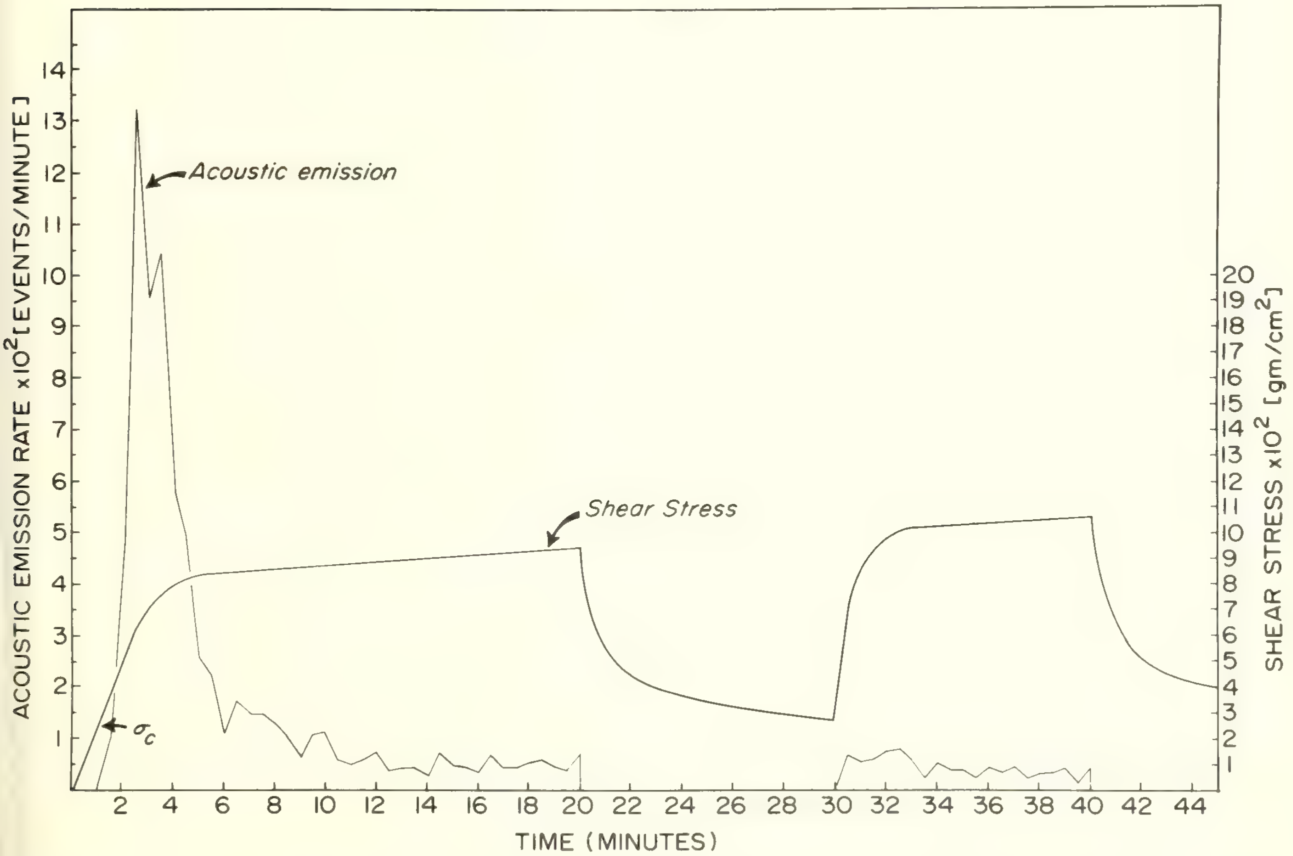


Figure 2. Acoustic emission rate response and shear stress response vs. time for a snow specimen deformed at a constant angular deformation rate of 2.2° per minute. The specimen was deformed for 20 minutes, allowed to relax for 10 minutes, and reloaded. Shear stress is calculated at the outer radius of the specimen.

being observed depending on the rate and mode of deformation (tension, compression, or torsion). Figure 2 will serve to point out the salient features of the emission response for this type of load history.

The snow used in these experiments was obtained from a collection area on relatively flat ground at a depth of about 1 meter. On this basis we will assume that the maximum stress that it had previously experienced was an overburden stress of 35 gm/cm^2. This fact is significant since prior load history is an important parameter in terms of acoustic response. As loading is initiated no acoustic response is observed until the stress reaches a certain level; this is depicted as σ_c in figure 2. As the stress increases above this value acoustic activity is initiated. The rate of acoustic activity then increases to a maximum which corresponds to the point in the stress deflection curve where the stress begins to fall off rapidly. With further deformation the rate of acoustic activity decreases steadily as the stress raches a steady state response. If the deformation is stopped, the acoustic activity ceases and the stress relaxes. If after a period of relaxation the snow is again subjected to further deformation at the same rate, the acoustic activity resumes at a rate nearly equal to what it was before deformation was terminated. This phenomenon has been observed for relaxation periods of up to 15 hours, which is the longest time that we have allowed specimens to relax before reloading. As indicated earlier, the basic acoustic emission response is similar for the three modes of deformation studied.

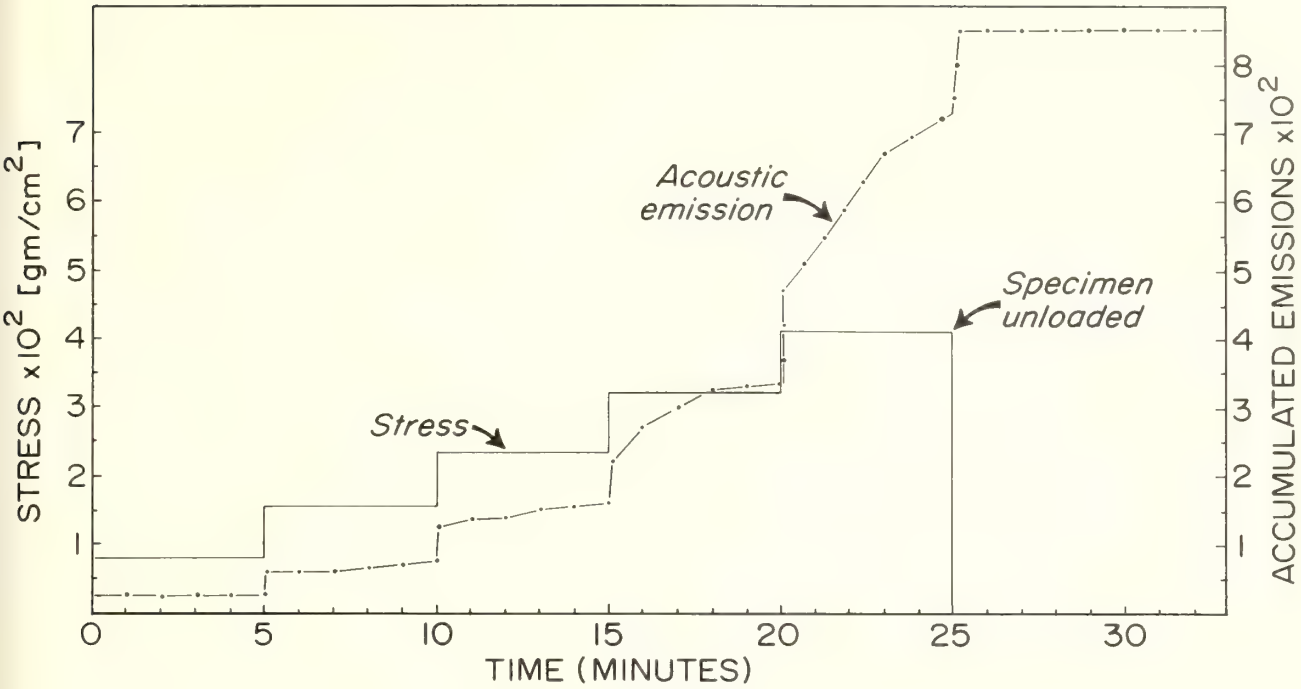
The acoustic emission response is very sensitive to the rate at which the snow is deformed. For relatively high rates of deformation, (that is rates close to those which induce fracture in the snow) the rate of emission rises to its maximum value and then decreases rapidly with continued deformation. Figure 2 shows the typical emission response for a high deformation rate. For very low deformation rates (rates several orders of magnitude below those which induce fracture) the acoustic emission rate curve does not show this rapid rise and decay. This rapid rise and decay feature becomes increasingly pronounced as the rate of deformation is increased.

In addition to constant deformation rate experiments a number of constant load tests in uniaxial compression and tension have been conducted and the acoustic response monitored. Figure 3a shows the acoustic response recorded for a snow sample subjected to a number of discreet load steps in uniaxial compression.

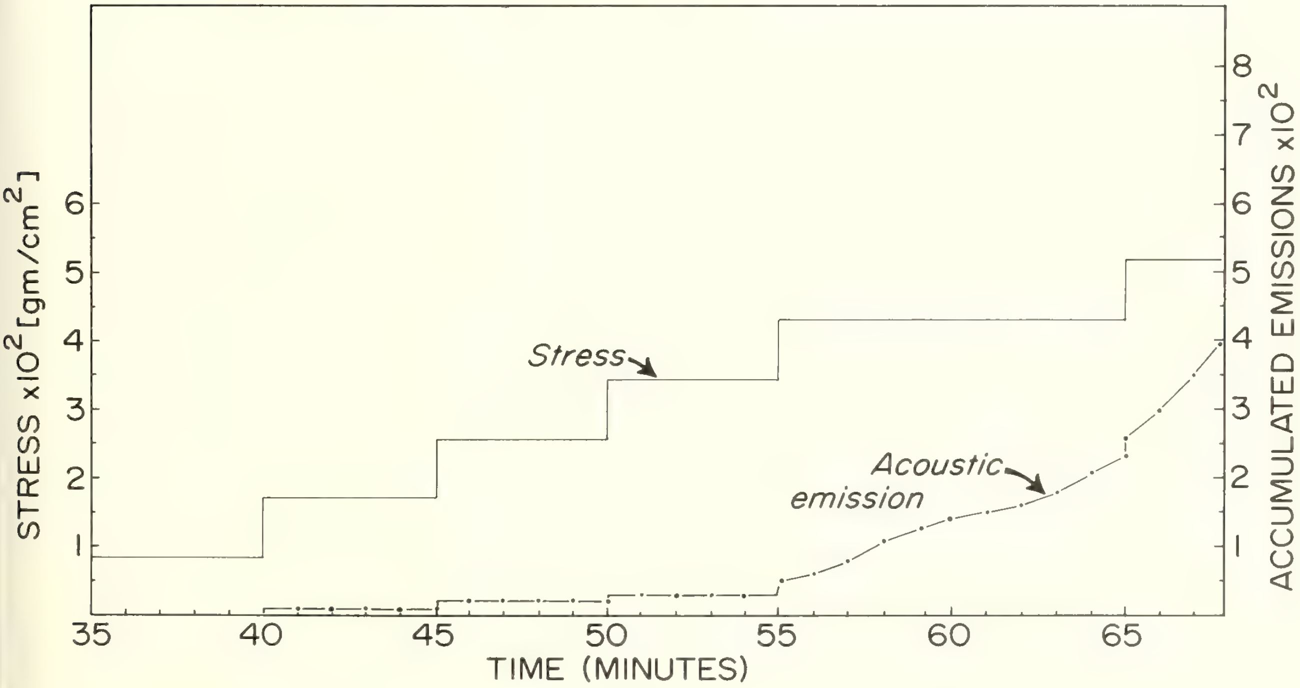
The acoustic response that is observed in creep experiments can be described as follows. For low stresses, below approximately 100 gm/cm^2 no emission activity is detected except for a few burst when the load is initially applied. If the stress is increased an incremental amount, to a level where activity is detected, acoustic emissions are observed throughout the region of primary creep. As the creep rate approaches a steady state the rate of acoustic activity decreases to a near zero value. Again it is important to emphasize that the snow used here was subjected to only overburden stresses prior to testing. Figure 3b shows the results of unloading the above specimen, allowing it to relax and then reloading it. Note that little or no acoustic activity is observed until the stress applied to the specimen is equal to or greater than the maximum stress it had previously experienced. This interesting phenomenon is known as the Kaiser Effect, and may have a possible application for measuring the state of stress in a snowslope.

Like the constant deformation rate the basic pattern of acoustic emission tends to be similar for both tension and compression at relatively low stresses. A number of tension creep tests have been conducted at relatively high stresses (stresses in the vicinity of 500 gm/cm^2) with some interestering results being observed. The results of one such test is reported here.

A specimen was incrementally loaded over a 100-minute time interval to a stress of 500 gm/cm^2 and the acoustic response observed. Within a minute after the load was applied to produce this stress in the specimen, the acoustic emission rate was 100 events per minute. Over the next 63 minutes the acoustic emission rate dropped to 25 per minute. The emission rate then showed some sign of increasing for the next 3 minutes. It then increased in a monotonic manner for 5 minutes to a rate of 169 events per minute, at which point the specimen failed catastrophically. This experiment was repeated with essentially the same result observed. The implication from this experiment is that for this type of load condition the onset of failure could be detected some minutes in advance.



(a)-Initial Loading



(b)-Reload

Figure 3. Accumulated acoustic emission response for a specimen subjected to an incremental load history: (a) Results of initial loading and unloading of snow sample; (b) Results obtained when specimen was reloaded.

Discussion

This paper has attempted to give a brief view of the acoustic emission phenomenon in snow. We have considered some possible emission sources and also presented the results of a number of laboratory experiments. In observing the acoustic emission phenomenon in snow, two possible applications in snow mechanics are suggested. As a purely empirical tool it appears that a great deal of information about stress and strain in an avalance slope may be gined by an acoustical monitoring system. Observations could be made both by placing transucers in an avalanche slope and making *in situ* observations and by removing samples and testing them in the laboratory. Using laboratory data as a basis, a comparative analysis could be made to interpret field data. One such test presently being investigated will utilize the Kaiser Effect to measure the state of stress over a period of time in a typical avalanche slope. If an oriented sample can be removed from the snowpacj without introducing spurious overstress in the process, it appears feasible that its *in situ* stress can be determined by controlled reloading in the laboratory.

A second possible research function of acoustic emissions would utilize this phenomenon, in conjunction with more standard techniques of experimental stress analysis, as an aid in the development of a constitutive relation for snow. At present the relation between acoustic emissions and the deformation mechanism in snow is not well understood. Consideration of the patterned acoustic response observed for various load and deformation histories indicates that it is related to the mechanical response. Since burst type emissions detected in snow originate from transient disturbances that take place in and between ice grains which compose the snow matrix, it appears reasonable to interpret the acoustic phenomenon at the structural level.

Acknowledgments

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INCORPORATION OF GLIDE AND CREEP MEASUREMENTS INTO SNOW SLAB MECHANICS

C. B. Brown, R. J. Evans, and D. McClung

ABSTRACT

The conventional field measurements in slab avalanche control include snow strength, creep, and glide. The snow strength appears naturally in any failure criterion, but the inclusion of creep and glide data into the slab mechanics is not obvious. Here, the physical features of creep and glide are discussed. This leads to possible models which can be incorporated into a continuum theory. As a result, definite suggestions are made concerning the range of parameters to be measured in the field.

Introduction

The solution of problems in snow slab mechanics can be based on the formulation of Perla and LaChapelle (1970) where some metamorphosis of either the snow ground interface or some surface in the snow slab causes a reduction in shear capacity. This approach has been further developed by Brown, Evans, and LaChapelle (1972) to find the state of stress in fallen snow and the dimensions of slab avalanches; this work provides no causality for the shear degeneration, and the boundary condition on the interface is described as zero normal motions and a definite shear stress. The solution used is linear elasticity theory.

The first shortcomings of the Brown, Evans, and LaChapelle work are: (1) The inability to model actual interface boundary conditions associated with definite metamorphosis; and (2) the inability to account for the nonlinear and temporal response of the snow. These two features are often included in the expressions, glide and creep. The object of this paper is to discuss the inclusion of these features into snow slab mechanics.

Glide

The relative motion between the ground surface and the juxtaposed snow will serve as a definition of glide. The motion is the measured translations over definite periods of time. It is natural to think of the onset of and subsequent motion being controlled by the laws of Amontons. These would mean that glide would not occur when

$$\tau < \sigma \mu_s \qquad [1]$$

where τ is the interface shear, σ the interface normal pressure, and μ_s the static coefficient of friction. When [1] becomes an equality, glide commences and the resistance to this motion is a shear

$$\tau = \sigma \mu_k \qquad [2]$$

where μ_k is kinetic coefficient of friction and $\mu_k < \mu_s$. One consequence of such laws is the monotonic increase of the glide speed with time. Examination of the results of Gand and Zupancic (1965) for glide near Davos indicates that the speed increases with time until a terminal value is attained. This speed is then maintained for the rest of the season. The results in figure 1 have a reverse trend inasmuch as the terminal speed is the decay from the high values of the earlier season. Clearly these two sets of readings from Davos and the Cascades are in conflict. However, they do refute the restraint equation [2]; the speed does stabilize in both cases, and the resistance must depend on the speed. Thus

$$\tau = f(v) \qquad [3]$$

where v is the glide speed. The functional form of [3] will apparently be completely different in the two cases discussed.

The small scale features at the interface consist of soft snow laid on a hard ground with the possibility of organic separation. The ground is rugged and, because of the differences between hardness of the ground and snow, it is unlikely that the usual concept of slipping can apply. Rowe (1964) has shown, for materials with very different hardness, failure is by shear in the softer material at a layer beyond the envelope of the rough surface. This means that failure

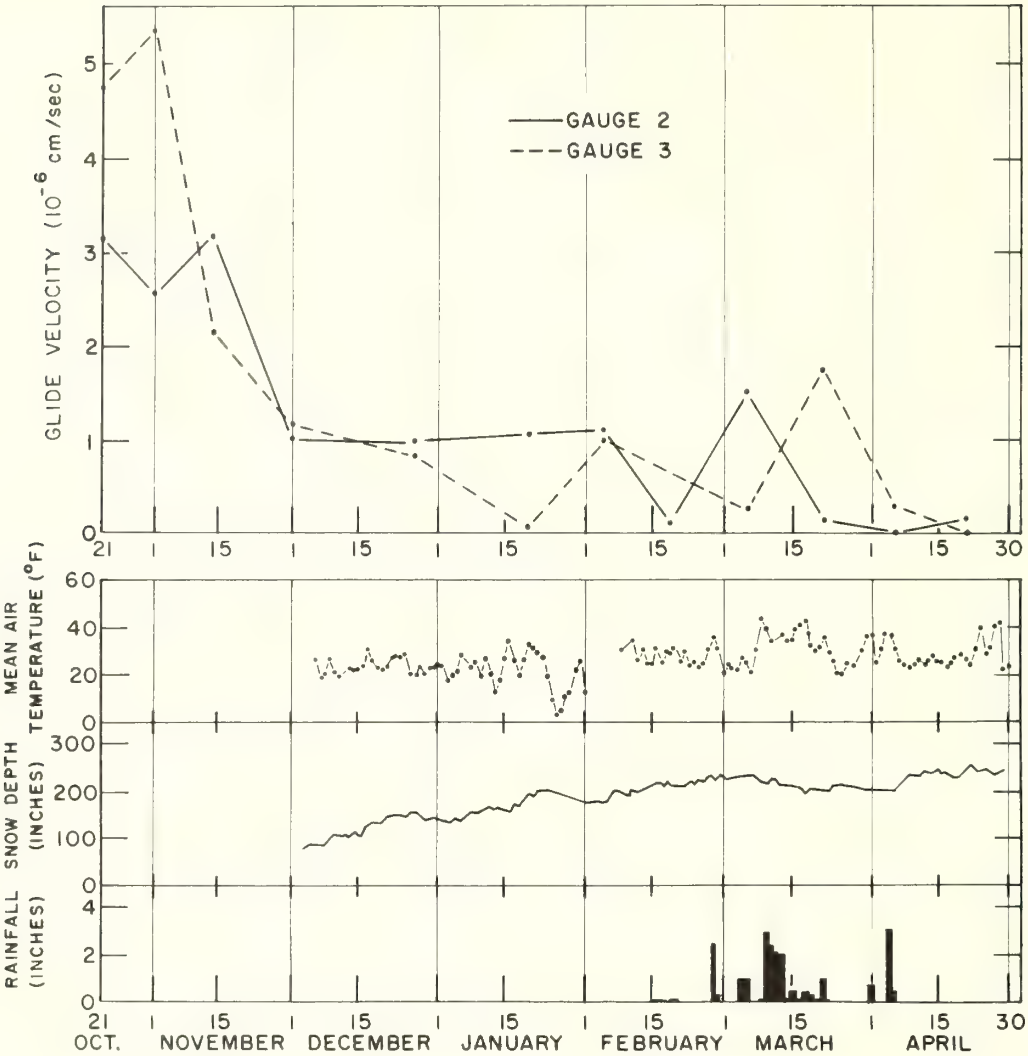

Figure 1. Glide measurements, 1971-72, Mt. Baker, Washington.

would be in the snow itself unless the organic layer was smooth and slippery or unless melt water appeared at the interface. Following up on Rowe's work, we would anticipate that the initiation of glide would be associated with the shear capacity of the snow. Here we would consider a sintered material with the conditions ripe for the application of the Bowden-Tabor (1958) theory of failure across the cohered interfaces of the grains. Unfortunately, in snow the phase state is dependent on the stress conditions as well as the temperature. The usual process of bond fracture at the interface occurs. This can be due to a combination of change of properties as well as the stress level. Healing may also happen. Thus, on the interface in the snow material a continuous process of healing and fracture, associated with regelation, must be expected.

The previous discussion suggests that once steady thermal and mechanical conditions exist near the interface, uniform glide speed should be attained. Until that steady state, the glide speed will depend on the presence of water, the organic layer, the snow condition, the slope and ground smoothness. Whether the glide accelerates to the terminal speed, as in the Davos work, or decelerates as in the work shown in figure 1, depends on these local conditions. The final steady speed will also be affected by the local conditions.

A conclusion concerning glide is therefore that a terminal steady speed will be attained once steady mechanical and thermal conditions exist. The prior speed will be closely associated with local characteristics.

A point with regard to the interpretation of field measurements of glide is worth noting. The glide velocity measured at a particular location depends not only on the interface conditions at that point but also on conditions at other locations on the moving interface, on the snow properties, and on the boundary conditions over the whole slope. Thus, meaningful comparison of results obtained at different sites and different geographic locations is particularly difficult.

Creep

This term is usually applied to deviatoric as well as dilational changes with time. The first is associated with the grains riding over each other, the second with grain readjustment toward a minimum bulk volume. Both processes are aided by the crystals tending to a spherical shape by loss of crystal branches due to vapor diffusion through the air spaces. The grain size decreases and the regime changes allowing local relocation and sliding to proceed rapidly. In spring time the process is aided by the intrusion of melt water from the surface. On a typical slope the creep occurs as motion parallel to and normal to the surface. Shear creep is manifested when the parallel velocity depends on the position of the snow. Dilational creep appears as settlement and uniform bulk motion down the slope. The strain rates in the two modes are of the same order of magnitude on avalanche slopes.

Figure 2 shows results of sawdust column tests in the Cascades. It is noted that the columns remain straight and that the shear creep strain rate is independent of position. This means that the shear strain is constant over the depth whereas the shear stress increases with depth; the constitutive law for the creep process of the snow is not that of a linear, homogeneous, isotropic material.

The creep speeds are of the same order as the measured glide speeds. Both features are therefore equally important in any analytical formulation.

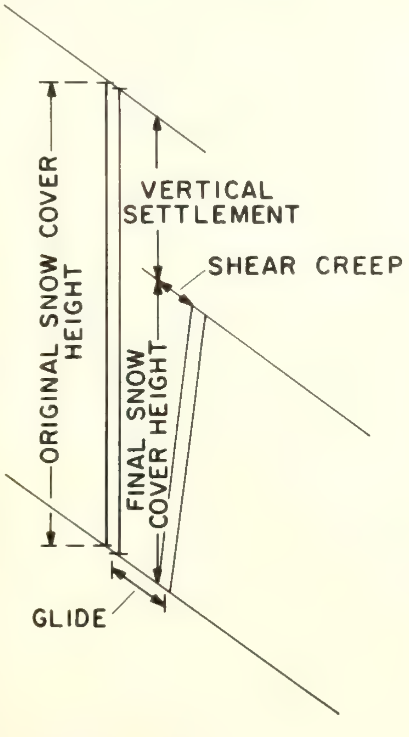

Figure 2. Typical creep experiment, Mt. Baker Site 3.

DURATION OF EXPERIMENT:
5.087×10^{6} sec (≈ 2 MONTHS)
SHEAR CREEP: 1.497×10^{-6} cm/sec
GLIDE: 0.2295×10^{-6} cm/sec
ORIGINAL HEIGHT: 422 cm
FINAL HEIGHT: 156 cm
SLOPE ANGLE: 30°, SOUTH-SOUTHWEST FACING SLOPE
TERRAIN: SHORT BRUSH AND GRASS

Glide Material

The glide boundary condition occurring with thermal and mechanical equlibrium appears to result in a uniform glide speed. At any time the total normal interface area, A, will be comprised of fluid and solid parts (A_F and A_S), thus

$$A = A_F + A_S \tag{4}$$

The area A_F may in fact include separated interface regions discussed by Lang and Brown (1973). The only requirement is that A_F is unable to sustain shear stresses; then the apparent shear stress during glide is

$$\tau = \frac{\tau_s A_S}{A} \tag{5}$$

where τ_s is the shear strength of the snow in the region A_F. This has a likeness to the Bowden-Tabor (1958) hypotheses. The area A_S will depend not only on the melting and freezing on the interface but also on the snow column weight. This affects the normal contact force on the sintered material considered here. An increase in normal force increases the contact area ($\bar{A}_S$) and results in a higher tangential force to cause incipient rigid body slip. Thus if N is the normal contact force, T the tangential force at the contact between two spheres at incipient slip, then

$$T = \mu_s N \tag{6}$$

and

$$\tau_s = \frac{T}{\bar{A}_S} \tag{7}$$

Because the increase in $\bar{A}_S$ with N is nonlinear, it is apparent that the value of τ in [5] is not only sensitive to the thermal state but also depends on the weight of the snow overburden. The importance of these aspects will vary from site to site.

A steady situation later in the season would be expected to produce an isothermal state, non-modifying snow properties and fixed snow overburden. A possible relationship at this steady state between the interface apparent shear, τ, and the finite glide speed v is

$$\tau = B\, v^{-1} \tag{8}$$

where v depends on A_S/A and B on the local conditions providing the values in [6] and [7].

Creep Model

Consideration of the material suggests that tractable problems in snow mechanics are generally of two types: (1) Those in which disturbances are of short duration and behavior is essentially elastic, and (2) those where loads are sustained for longer times and viscous flow is significant compared to initial elastic motions. For type (1) indications are that at least for low stresses a linear elastic law may be justifiable (Brown et al. 1972). For type (2), consideration of the material as either nonlinear or inhomogeneous lead to motions consistent with those observed. These two forms of steady creep law are investigated here.

For this purpose we will assume uniform slope and snow depth and constant snow density, ρ. Coordinates are as shown in figure 3 where an infinite extent in the x_2 plane exists. Then the known stress components, τ_{ij}, (Brown et al. 1972) are:

$$\tau_{12} = \rho \sin\Theta \, x_2 \tag{9a}$$

$$\tau_{22} = -\rho \cos\Theta \, x_2 \tag{9b}$$

$$\tau_{13} = \tau_{23} = 0 \tag{9c}$$

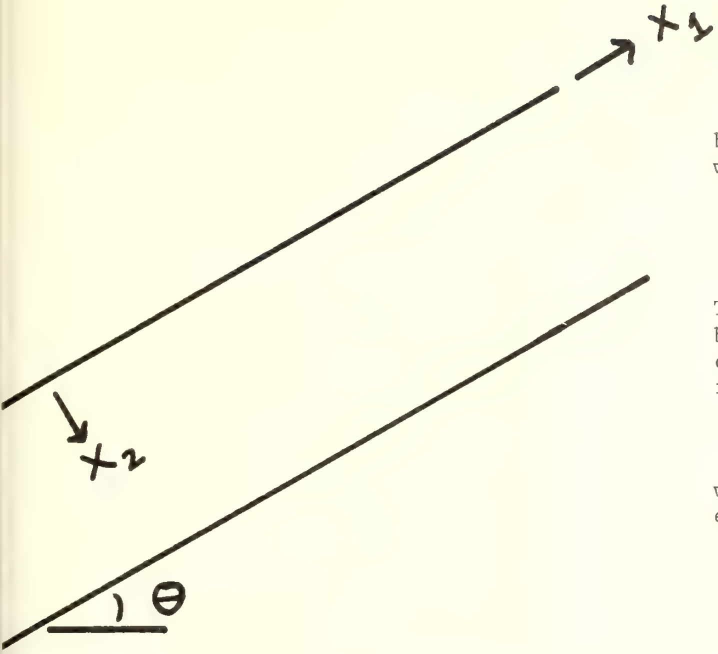

Figure 3. Coordinate system for creep model of long uniform slope.

Known strain rate components, d_{ij}, are:

$$d_{12} = k_1 \qquad [10a]$$

$$d_{11} = d_{33} = d_{13} = d_{23} = 0 \qquad [10b]$$

based on our experimental evidence (figure 2), we assume k_1 is constant.

Thus only d_{22}, τ_{11}, and τ_{22} are unknown.

(a) Nonlinear Isotropic Constitutive Law.--To model an isotropic homogeneous relation between stress and strain rate for steady creep, we assume a constitutive law of the form (Salm 1967):

$$\tau_{ij} = F_1 \delta_{ij} + F_2 d_{ij} \qquad [11]$$

where F_1 and F_2 are functions of the independent strain rate invariants I_1 and I_2 and where

$$I_1 = d_{kk} \qquad [12]$$

$$I_2 = \frac{1}{2} d_{ij} d_{ij} \qquad [13]$$

From [10], for the state of deformation under consideration,

$$I_1 = d_{22} \qquad [14]$$

$$I_2 = d_{22}^2 + 2k_1^2 \qquad [15]$$

From [11]

$$\tau_{12} = F_2 k_1 \qquad [16]$$

which, using [9a] and [10a], give

$$F_2(d_{22}, d_{22}^2 + 2k_1^2) = \frac{\rho \sin\Theta}{k_1} x_2 \qquad [17]$$

Clearly, the dependence of τ_{22} on x_2 must be known before proceeding further. This information is not presently available, however, and the general relation $\tau_{22}(x_2)$ will be assumed. It may readily be shown that [17] cannot be satisfied if d_{22} is constant. Assuming

$$d_{22} = k_2 x_2 \qquad [18]$$

where k_2 is constant, then [17] can be most simply satisfied if

$$F_2(I_1, I_2) = \alpha I_1 \qquad [19]$$

where α is a material constant.

Satisfaction of [9b] places restrictions on F_1 which using [11] become

$$-\rho\cos\Theta \, x_2 = F_1 + \alpha(k_2 x_2)^2 \qquad [20]$$

[20] is most simply satisfied if

$$F_1(I_1, I_2) = \beta I_1 - \alpha I_1^2 \qquad [21]$$

and hence the simplest form of [11] consistent with observations is

$$\tau_{ij} = (\beta d_{kk} - \alpha d_{kk}{}^2)\delta_{ij} + \alpha d_{kk}\, d_{ij} \qquad [22]$$

and in terms of α and β the parameters of deformation, k_1 and k_2, are given by

$$k_1 = -\frac{\beta}{\alpha}\tan\Theta \qquad [23]$$

$$k_2 = -\frac{\rho\sin\Theta}{\beta} \qquad [24]$$

(b) Inhomogeneous Constitutive Law.--The observed shearing deformation will occur if

$$\tau_{12} = 2\Sigma d_{12} \qquad [25]$$

where Σ is a material constant which increases linearly with depth and is zero on the upper surface. Such inhomogeneity would result if the flow law for steady creep were of the form

$$\tau_{ij} = \lambda\delta_{ij} + 2\Sigma\, d_{ij} \qquad [26]$$

where λ and Σ are material constants which depend on invariants of the state of strain, that is, stress-induced inhomogeneity. The observed deformation would occur if Σ were linear in volumetric strain (or hydrostatic stress).

Argument (b) for inhomogeneous material provides a simpler explanation of the observed shearing motion than argument (a). For this reason, it must be preferred at this stage. Provided that λ and Σ are strain or stress dependent, then [26] still describes nonlinear material behavior. For some stages of creep, however, where the state of stress remains constant, the behavior will be equivalent to that of an inhomogeneous isotropic material. Clearly, further experimental evidence is required before more definite conclusions may be drawn with regard to the constitutive law for steady creep.

Avalanche Prediction

From the hypothesis of Perla and LaChapelle (1970) and the subsequent full analyses (Gand and Zupancic 1965), it is clear that one avenue of avalanche prediction concerns the attenuation of basal shear capacity. The regelation model suggested here for the steady speed case would mean that over a substantial total interface area A some part will be melted and some frozen. Additionally, separation may occur. Under these circumstances [4] and [5] apply. Over A_F the shear capacity will be zero whereas over A_S the capacity at incipient sliding will be τ_s. This will reduce when a value $\mu_k \leq \mu \leq \mu_s$ is introduced into [6]. Averaged over the interface, this will account for some regions slipping locally and some just on the point of slipping. A consequence is that as A_S/A decreases, the apparent shear capacity, τ, decreases and the glide speed increases. Thus the physical model for glide resistance of Gand and Zupancic (1965) and by figure 1 can be explained by the hypothesis of [5]. In this case, our interest is in the sense of the ration A_S/A and hence in the sign of the rate of change of glide speed with respect to time. When the glide speed is increasing, with no additional evidence of increase in snow strength, then conditions of incipient avalanching should be expected. With decreasing glide speed, the slope should be stabilizing. In figure 1 the increasing glide speeds in February forecast periods of danger because of the increase in A_F; the decreasing speeds in February and March give rise to confidence in the snow slope stability.

Acknowledgments

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MATERIAL PROPERTY AND BOUNDARY CONDITION EFFECTS ON STRESSES IN AVALANCHE SNOWPACKS

J. O. Curtis and F. W. Smith

ABSTRACT

A linear elastic finite element computer program was applied to determine the stress distributions in multilayered snowpacks typical of those found at Berthoud Pass, Colorado. The effect on stress distribution of wide variations in elastic material properties was examined. Also, an attempt was made to model the shear failure of a weak sublayer in the snowpack by relaxing the condition that the bottom snow layer be firmly attached to the ground.

Introduction

This paper discusses the progress made in a joint research effort between the Rocky Mountain Forest and Range Experiment Station and Colorado State University to develop a mathematical model for the prediction of stresses and displacements in an avalanche snowpack. In this work, the finite element method is being used to provide a flexible stress analysis tool which can easily accommodate the geometric complexities of a realistic snowpack. At present the finite element model only accounts for elastic effects and therefore ignores the realistic effects of creep and plasticity. In spite of this limitation a considerable amount of insight to the stress distribution may be gained by such analysis, and to this end the following work is presented.

A set of numerical experiments were conducted on the finite element model. The purpose of these experiments was to predict the variations in stress distribution which result from varying both the material properties of the snow and the boundary conditions along the bottom of the snowpack. This work is an extension of previous work by Smith (1972) in which the type of boundary condition along the bottom of the snowpack was very restrictive and in which the study of material property effects was incomplete.

In earlier studies the bottom layer of the snowpack was assumed to be firmly attached to the ground. To simulate a weak sublayer the modulus of elasticity of the bottom layer was taken to be an order of magnitude smaller than for the rest of the snowpack. An attempt has been made in the present work to refine the modeling of the weak sublayer condition by application of shear and normal stress perturbations to the bottom layer, an idea investigated by Perla and LaChapelle (1970). This is an attempt to model a condition in which a shear failure has occurred along the bottom of the snowpack.

There has been considerable interest in the orientation of the principal axes of stress, particularly in the region of the fracture line. This paper also presents information regarding the influence of varying material properties and boundary conditions on the principal stress directions.

Problem Statement and Analysis Technique

The analytical model was applied to a multilayered snowpack (fig. 1) found on Berthoud Pass, Colorado, U.S.A. Layer densities are labeled and the region of primary concern is shown. This snowpack was measured and observed during the winter of 1965-66 by members of the Rocky Mountain Forest and Range Experiment Station. A natural avalanche did take place on this location with the observed fracture line noted in figure 1.

The finite element computer program, utilizing triangular constant strain elements, was applied with the following assumptions:

1. Plain strain conditions exist in the snowpack.
2. The top surface is stress free.
3. Each layer is isotropic.
4. A constant value of Young's modulus and Poisson's ratio exists throughout the snowpack.

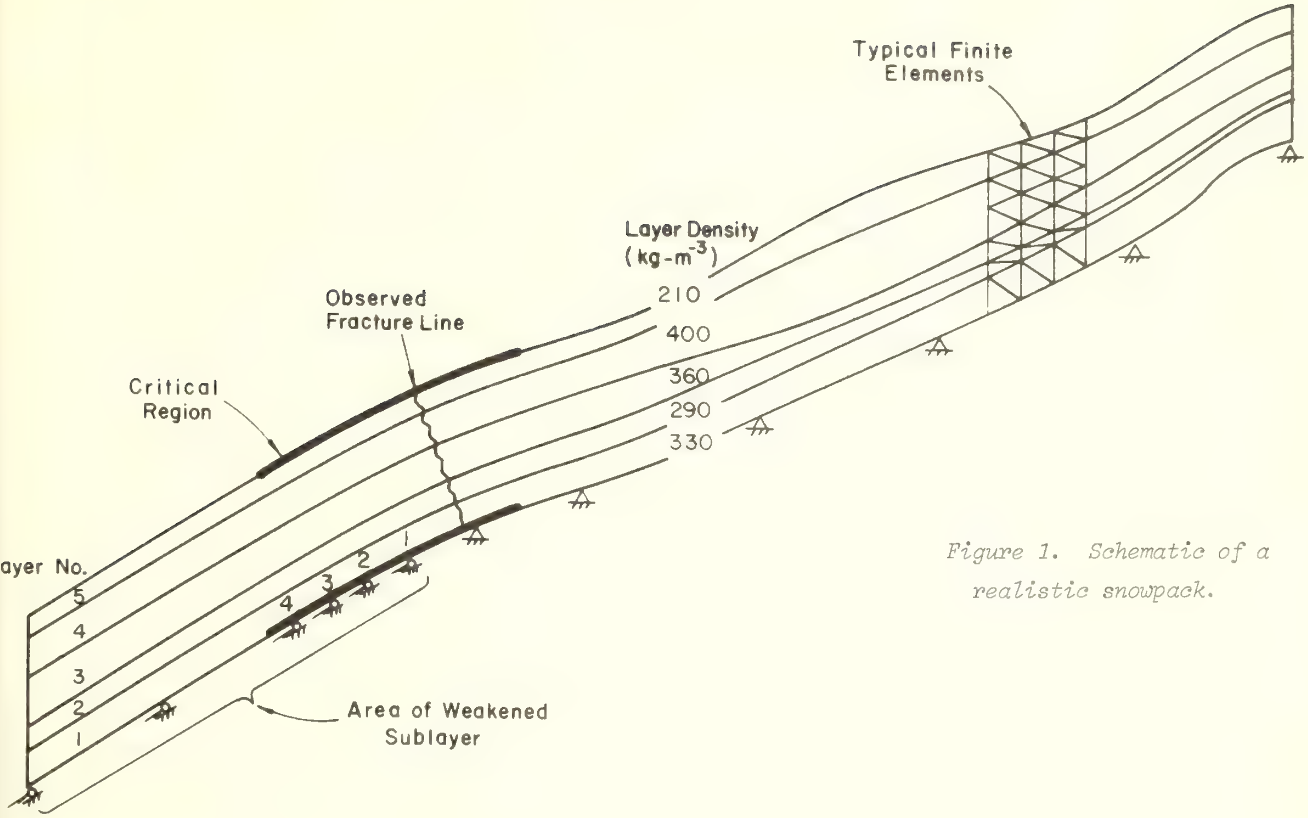


Figure 1. Schematic of a realistic snowpack.

A realistic snowpack such as the one shown in figure 1 is much longer than the figure indicates. In order to minimize possible errors due to truncating the snowpack, the approximate stress distribution due to Mellor (1968, p. 43-44) was applied to the left and right hand ends.

For part of the studies, a shear failure in a weak sublayer was assumed to exist over the area shown in figure 1, and was simulated by the following procedure. In the finite element method, as applied here, the snowpack is divided into triangular subregions with nodes at the vertices of each triangle. Once the numerical solution to a particular problem is complete, the stress and strain throughout each element as well as the net force and displacement at each node is known. To model the shear failure a computer run was first made in which the nodes along the bottom of the snowpack were assumed to be rigidly attached to the slope. This is called the "baseline" condition. The forces acting on the bottom nodes were then isolated for special study. The tangential components of these forces were reduced, and a new computer run was made to simulate a shear perturbation which might occur along the bottom of a snowpack due to the presence of a shear failure in a weak sublayer. For the present analysis, the forces were reduced in the following way (fig. 1): node point 1 had 100 percent of the baseline force applied to it; node point 2 had 90 percent, node point 3 had 80 percent, while node point 4 and the remaining bottom nodes had 70 percent of the "baseline" force applied.

This pattern of reduced forces is only one of many possible combinations which might be tried. The attempt here has been to determine whether this approach to modeling the weak sublayer has any validity at all in terms of the type of stress distribution produced compared to that expected based on field experience.

Results

Computer runs were made to predict the stress distribution within the snowpack for several combinations of values of the material properties (Young's modulus, E, and Poisson's ratio, ν). Analyses were performed for the "baseline" boundary conditions and for conditions for a shear failure in a weak sublayer. The following tabulation summarizes the cases which were run:

	Baseline			Shear Failure in a Weak Sublayer		
Young's Modulus $N\text{-}m^{-2}$	Poisson's Ratio			Poisson's Ratio		
	0.0	0.25	0.45	0.0	0.25	0.45
2×10^7	X	X	X	X	X	X
2×10^8		X				
2×10^9		X				

Effects of Material Properties.--Varying Young's modulus, E, had no effect on the stress distribution as long as the value of E was held constant throughout the snowpack. The reason for this is that the finite element method computes displacements as a function of the inverse of Young's modulus. Then stresses are computed as a function of E multiplied by the estimated displacements so that the effect of Young's modulus disappears.

The effect of Poisson's ratio on stresses in the snowpack is shown in figures 2 through 4. In these figures, the top graph presents the variation of the principal and maximum shear stresses with position along the top layer. The center diagram shows line segments which are alined with the direction of maximum principal stress. The lower graph presents the variation of the principal and maximum shear stresses with position along the bottom layer.

Two trends should be noted in these figures. First, values of principal stresses in the bottom layer become more compressive with increasing Poisson's ratio. The second trend to note is that there is a reorientation of the principal elements in the critical region of the snowpack. An examination of the principal element directions in the lower layer of snow shows that as Poisson's ratio increases, the principal directions rotate in a clockwise manner. The rotation is so great that for a Poisson's ratio of 0.45, the principal elements all lie at an angle of nearly 45° with respect to the slope of the layer below the observed fracture line. Remembering that the plane of maximum shear is oriented at an angle of 45° to the direction of maximum principal stress, it may be concluded that if a failure were to occur in the bottom layer of snow, it could occur as a shear failure. This result is interesting in light of a snowpack failure theory in which it is presumed that avalanche release initiates as a shear failure in a lower layer below the fracture line producing a tensile failure at the fracture line.

To carry this point further, one should compare the stress distribution resulting from the "baseline" runs with experimentally derived failure envelopes. Let us examine the maximum shear values found in lower layers below the observed fracture line for the $\nu = 0.45$ case.

Figure 8 shows that maximum shear stress value for layers 1 and 2 do lie within the shear failure envelope as constructed by Mellor (1966), while shear values for the other layers do not. Thus it is conceivable that shear failure could take place in either of these two layers. Field observations after the avalanche had released revealed that a shear failure did take place between layers 1 and 2.

One important difference between the shear stresses in these two layers is that the directions of maximum shear are different. Maximum shear in the bottom layer is oriented parallel to the hill's slope below the fracture line. This is not the case for layer 2. Therefore, one would expect that if a shear failure was to occur in the bottom layer, it would be in a direction parallel to the ground surface, while in layer 2 it would not.

It is also interesting to note that for all values of Poisson's ratio for "baseline" sums, the maximum principal stresses in the top layer tend to be tensile near the fracture line, but are not oriented parallel to the top surface. It might be reasonable to expect that the principal direction should be parallel to the top surface in order to produce a fracture plane upon failure which is perpendicular to the snowpack.

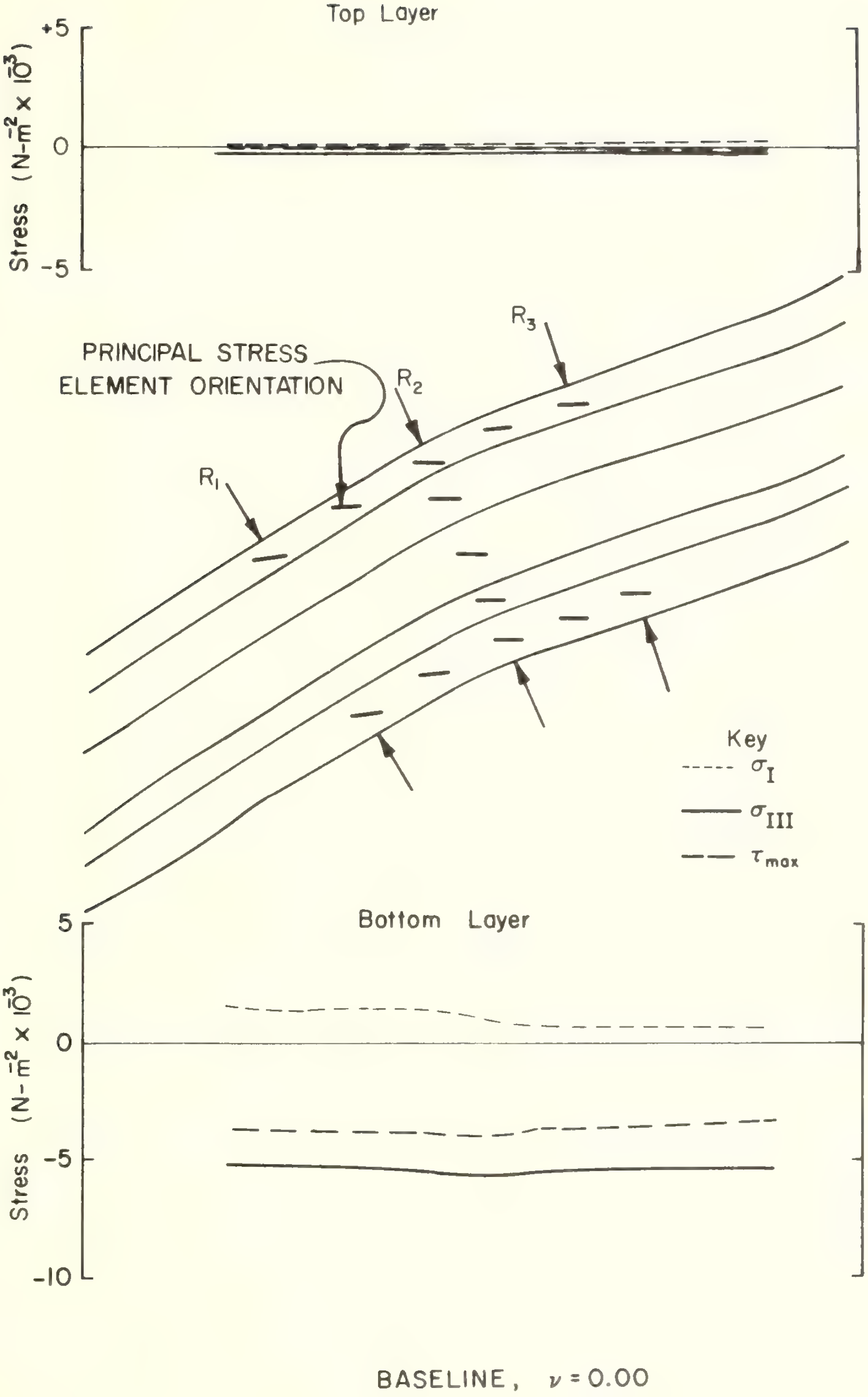


Figure 2. Principal stress magnitudes and directions.

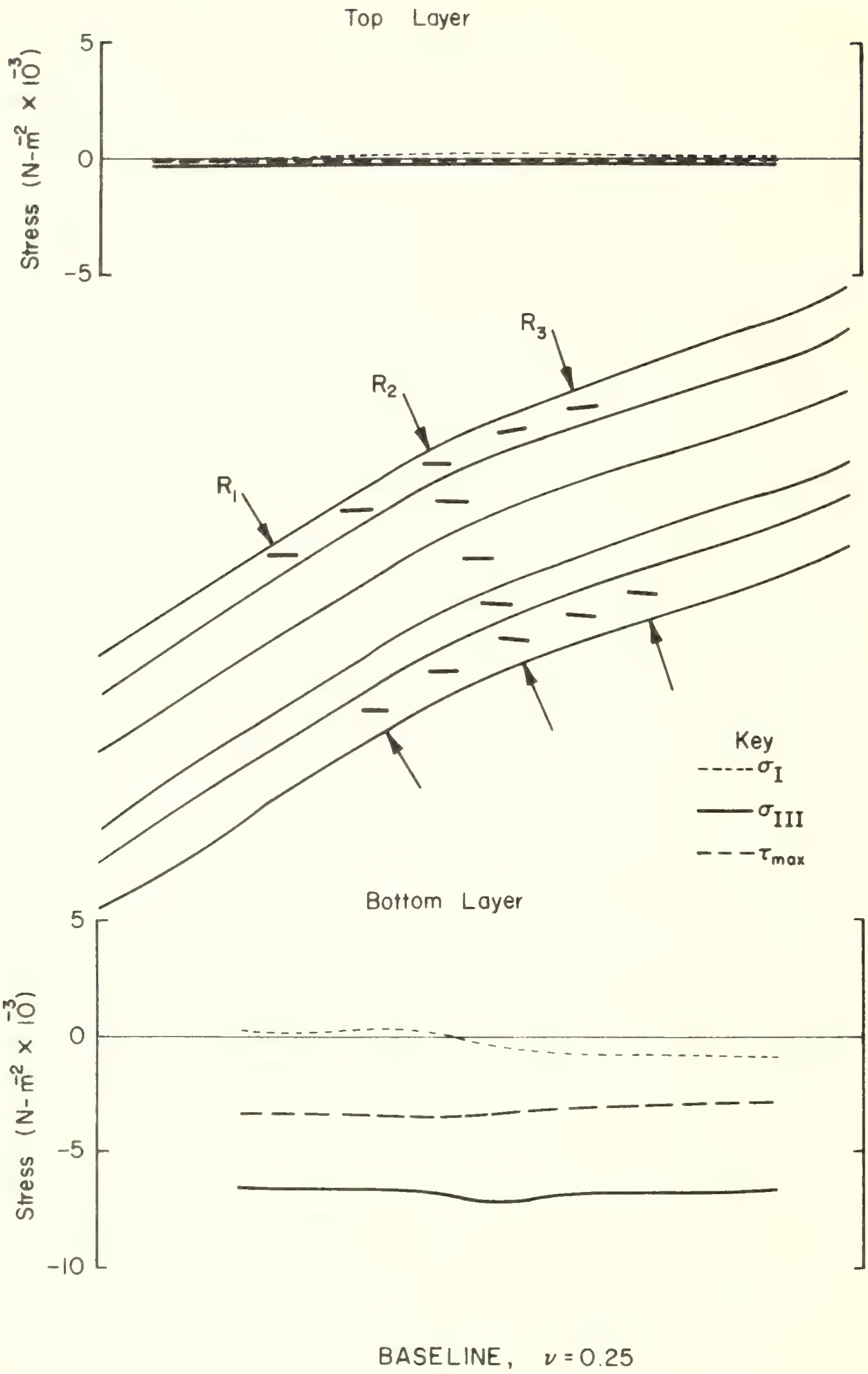


Figure 3. Principal stress magnitudes and directions.

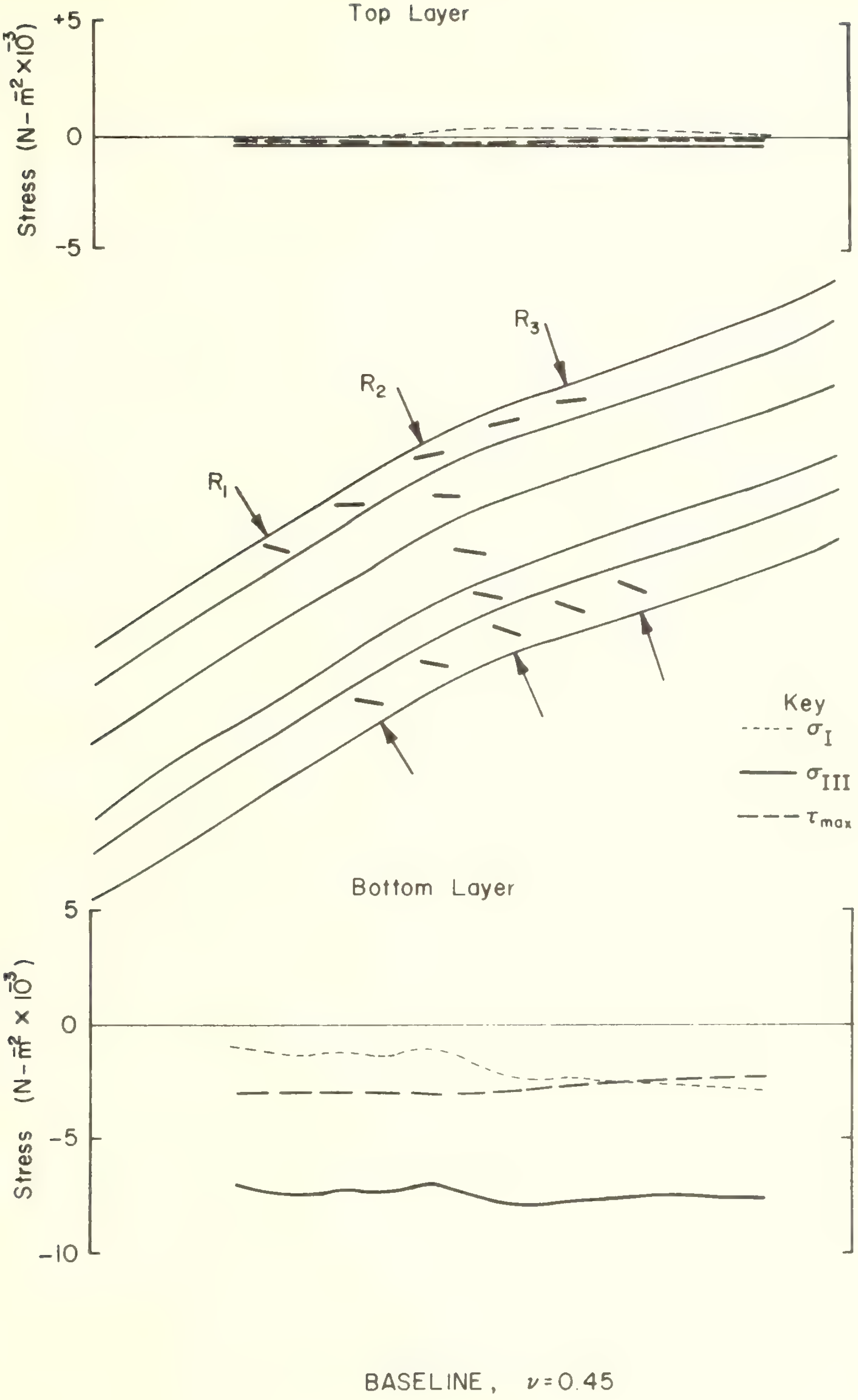


Figure 4. Principal stress magnitudes and directions.

Figure 5 presents the "baseline" run for Poisson's ratio of 0.25 plotted in a different way to illustrate the variation of stress through the snowpack in a direction perpendicular to the snow surface. A stepwise linear variation in the stresses is noted. This is due to the fact that the stresses are heavily controlled by the snow density. Since the density of each layer is different, the slope of the stress variation in that layer is expected to be different.

Effects of a Shear Failure in a Weak Sublayer.--Figures 6 and 7 graphically display the results of reducing tangential loads at the base of the snowpack to model the shear failure. There are two primary effects to be noted. The first and most obvious effect produced by the weakening of the sublayer is to create a stress concentration just below the observed fracture line. Comparison of figures 3 and 6 for a typical value of Poisson's ratio clearly demonstrates how the stresses change in the snowpack as a result of weakening the bottom layer. Along the top layer, the state of stress changes from one of near zero stress to one in which the maximum principal stress is fairly large and tensile. One also finds that the principal element in the reduced load case is directed parallel to the top surface. Both observations tend to support the theory of avalanche release that points to a shear failure in the snowpack followed by a tensile failure near the surface as the release mechanism.

Changing Poisson's ratio affected the reduced load stress distribution in nearly the same way that it did for baseline runs. Without referring to additional figures, the analysis showed that increasing Poisson's ratio had little effect on principal stress magnitudes for the shear failure calculations, but that there was a reorientation of the principal elements. Increasing Poisson's

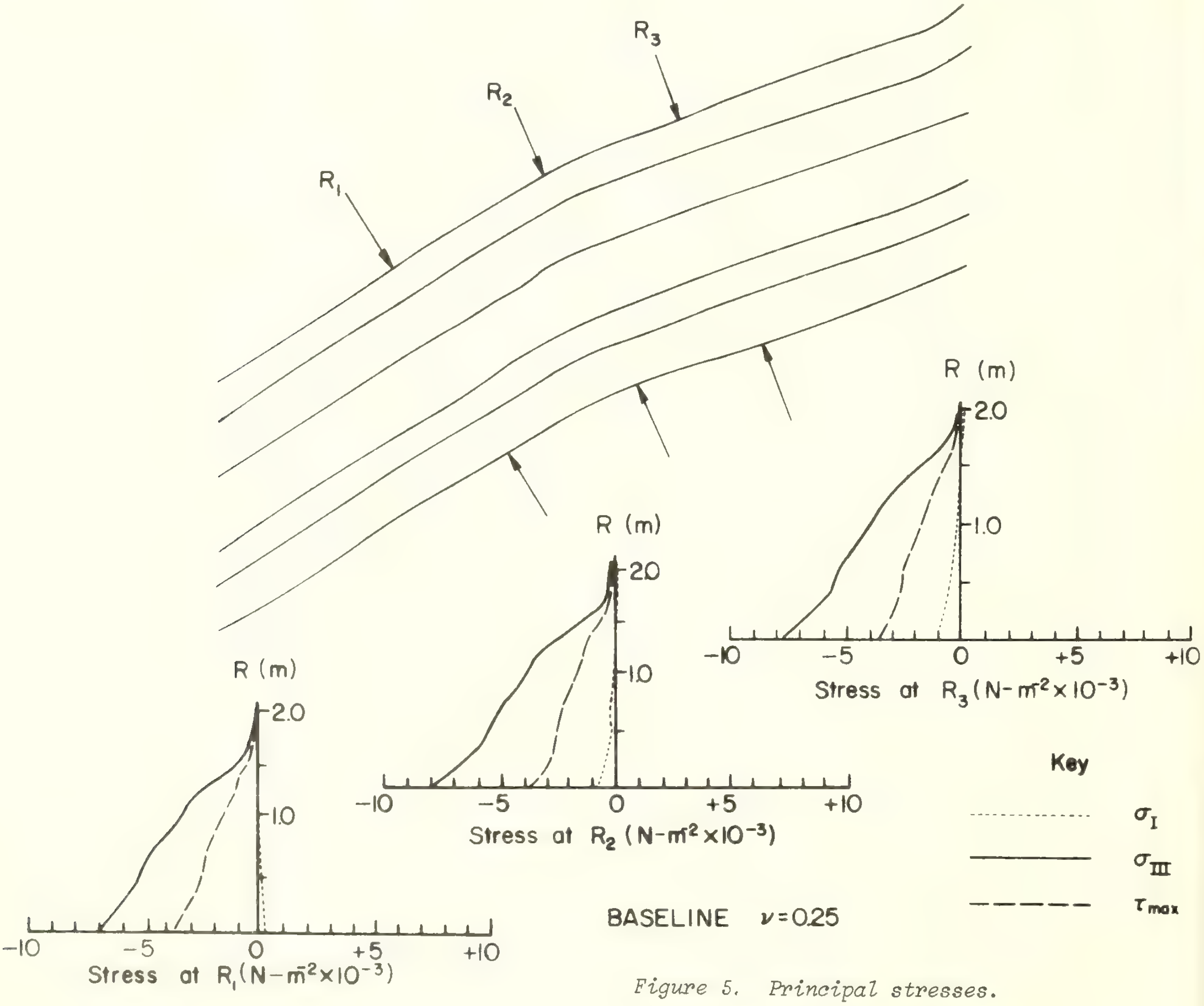
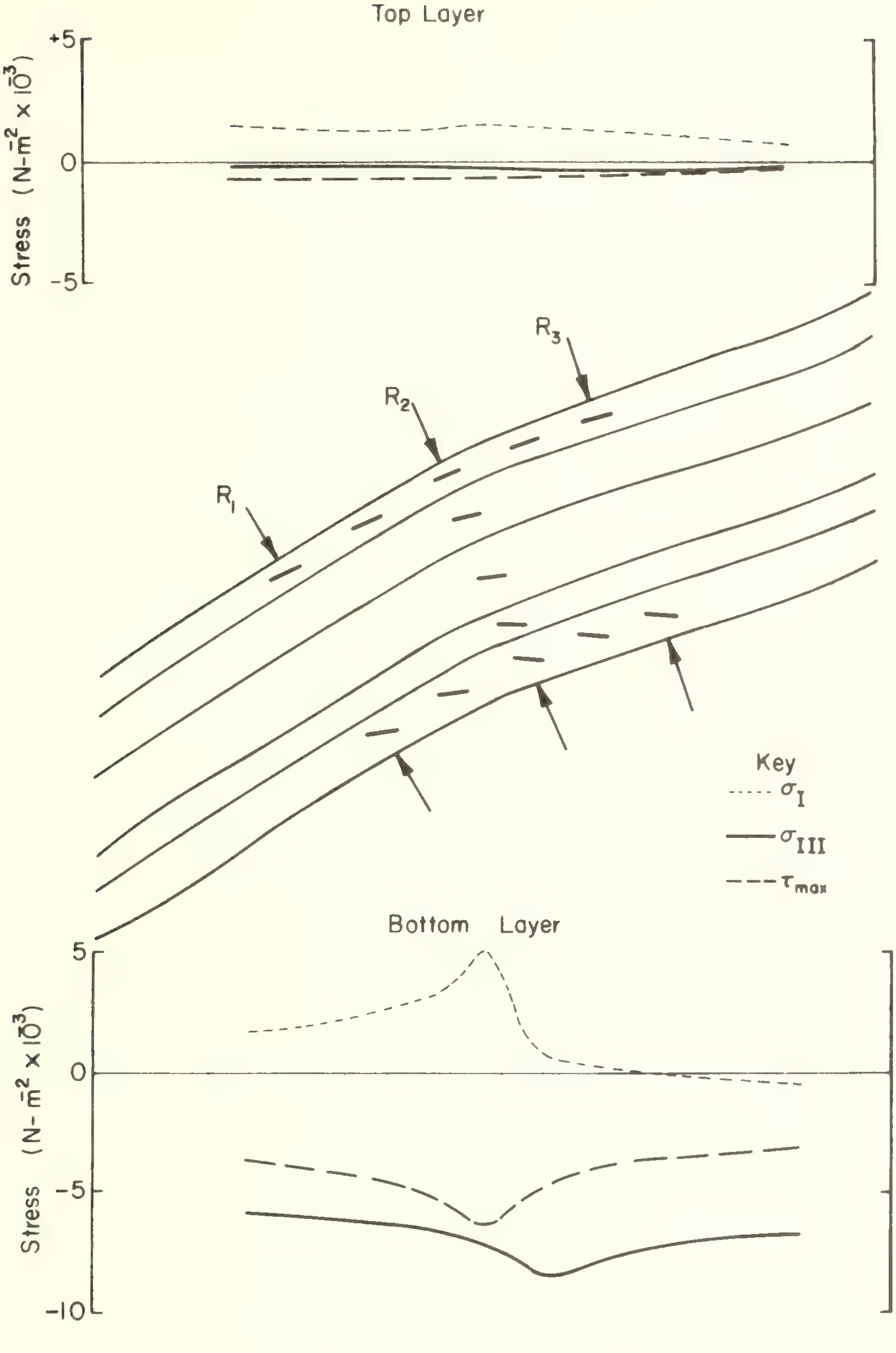


Figure 5. Principal stresses.



WEAK SUBLAYER, ν=0.25

Figure 6. Principal stress magnitudes and directions.

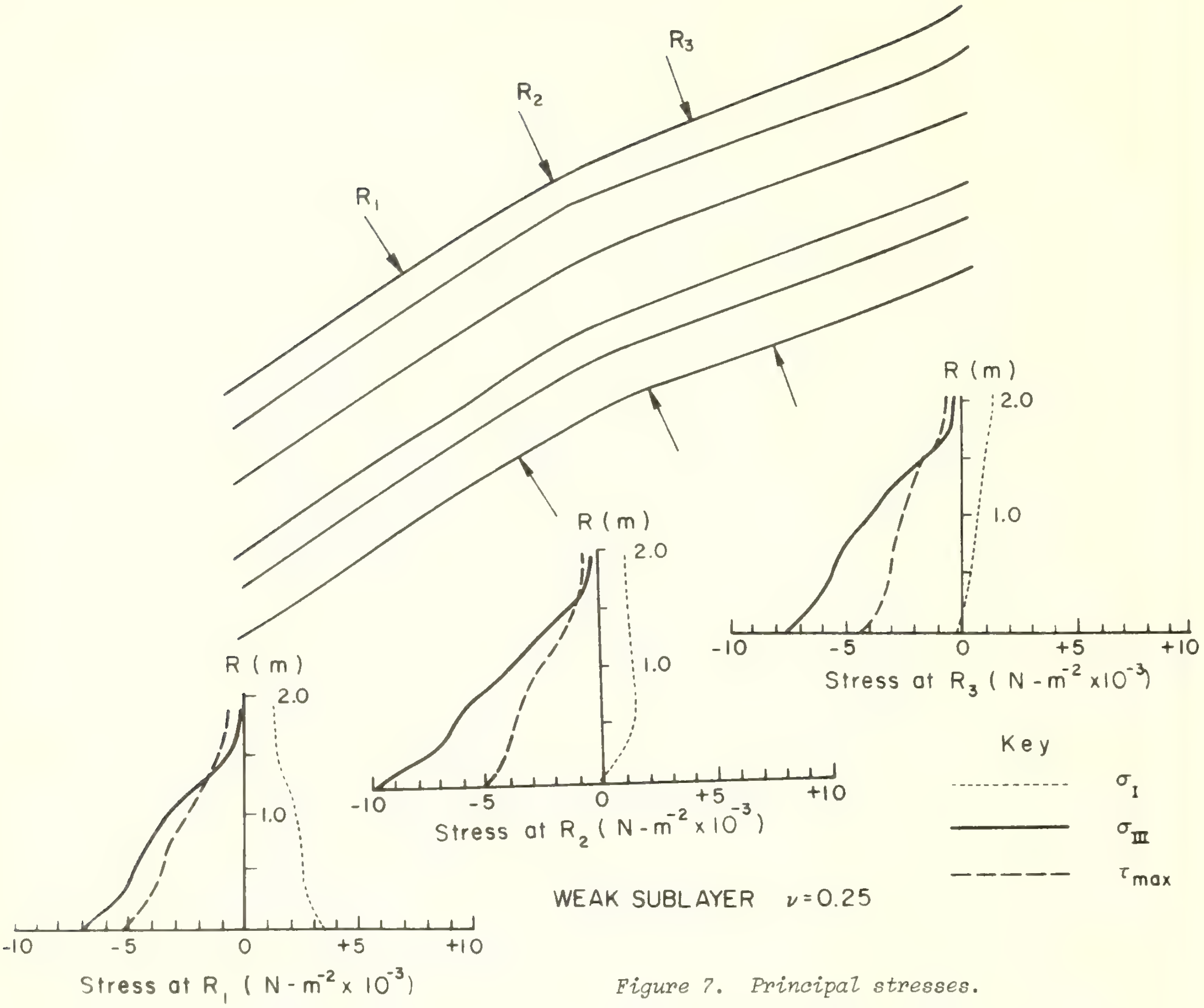


Figure 7. Principal stresses.

ratio caused a small clockwise rotation of the principal elements in the bottom layer, but had no effect on principal stress directions in the top layer. It should be made clear, however, that the state of stress in the lower layer was no longer one of maximum shear oriented parallel to the slope, since the shear failure simulation resulted in a redistribution of stresses.

Summary and Conclusions

Conclusions that can be drawn with respect to the effect of varying material properties are:

1. Varying a uniform Young's modulus does not influence the stress distribution in the snowpack.
2. Increasing Poisson's ratio makes the principal stress values more compressive, while for the most part rotating the principal elements in a clockwise direction.
3. Layers of variable density snow influence the variation of stresses as a function of depth. Density will play an even greater part when Young's modulus and Poisson's ratio are made functions of this parameter.

The above analysis was not an attempt to verify any particular avalanche failure theory; however, two conclusions can be drawn that tend to substantiate field observations of this and other avalanche snowpacks. First, the baseline runs revealed that a shear failure could have taken place in the bottom layer of snow below the observed fracture line. Post-release investigations of the actual snowpack revealed that such a failure did take place. Another important result of the

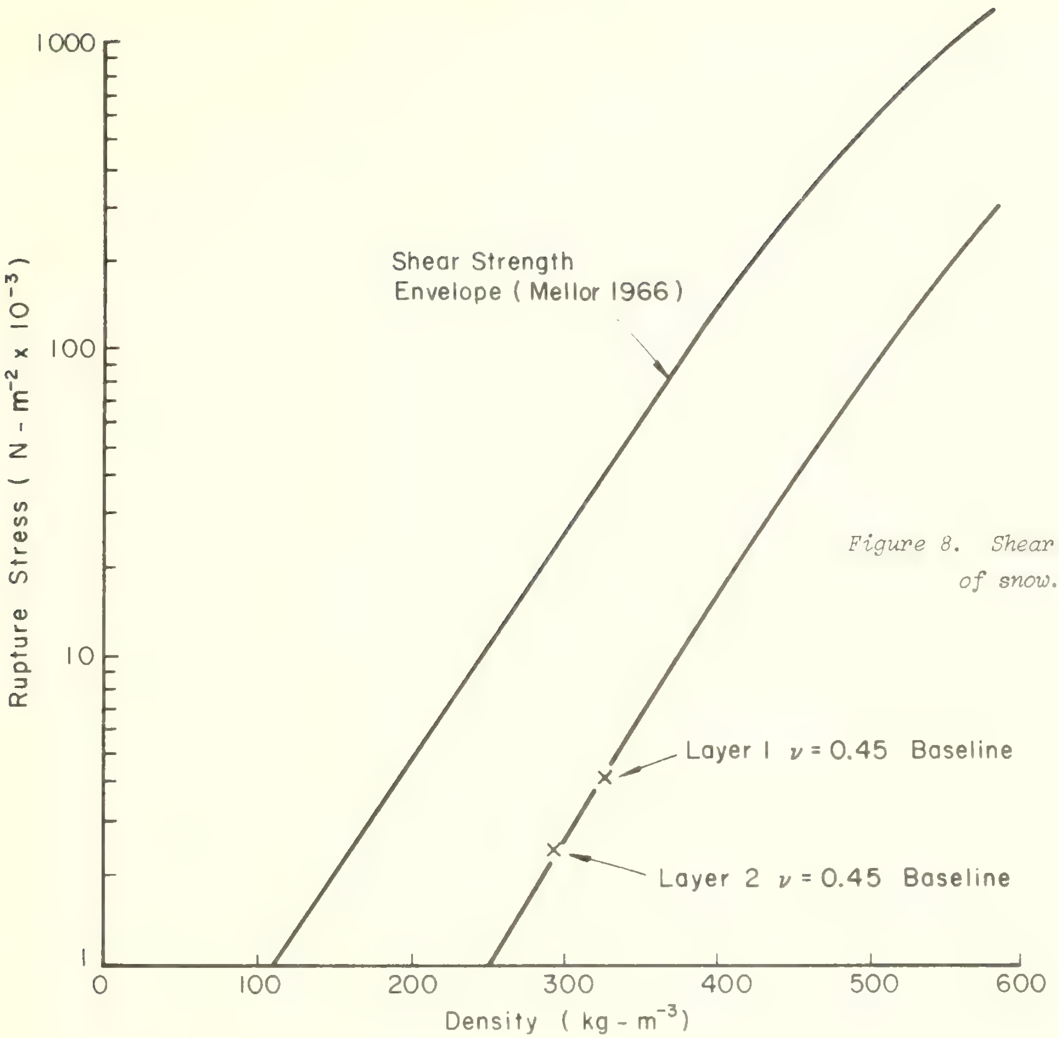


Figure 8. Shear strength of snow.

analysis is that through shear failure simulation, large tensile stresses parallel to the snow surface can be generated within the top layer of snow. This condition might lead to tensile failure in the critical region. Once again, field observation verified such an occurrence.

Acknowledgments

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ON THE MECHANICS OF THE HARD SLAB AVALANCHE

T. E. Lang and R. L. Brown

ABSTRACT

The buckling of snow slabs is proposed as a failure mechanism of avalanche slopes. Preliminary results indicate that buckling may initiate and grow under a wide range of conditions. To study the problem further, nonlinear constitutive equations and nonlinear failure theories are being considered. Acoustic emission techniques will be used to characterize the behavior of snow.

Introduction

Various factors contribute to the recognized uncertainty over the mechanism of hard slab snow avalanche release. Perhaps the greatest difficulty is the hazard of field observation of other than the crown region of an avalanche-sensitive slope. Additionally, downslope preavalanche material and conditions of geometry are largely obliterated following the avalanche. The upslope or crown region postavalanche geometry remains intact, and has been monitored and studied in some detail. Theories of release have been formulated assuming initial disturbance in the crown region, as by a tensile stress fracture, and subsequent propagation downslope (Sommerfeld 1969).

Snow, not being an easy material to characterize rheologically, has complex load-deformation properties and exhibits unique structure changes under certain thermal history conditions. In general, load, deformation, microstructure, and thermal characteristics of snow *in situ* on slopes have not been systematically measured, so that quantitization of factors relevant to subsurface conditions are not known. However, recognizing the fact that physical changes occur in the interior of snowpack, release theories have been formulated based upon some type of basal layer inhomogeneity. It is assumed that material transformation or a form of inclusion produces a weakened state or an unstable structural configuration. Either from local collapse or a shear failure, the release ensues (Bradley and Bowles 1970, Haefeli 1966, Roch 1966). Recent work which supports this concept of a weak sublayer are the theoretical studies of the stress state associated with this geometry (Perla 1971, Brown et al. 1972a), and an order-of-magnitude evaluation of the feasibility of a buckling mechanism contributing to the enhancement of slope failure (Lang et al. 1973). These studies relate to subsurface and toe region influence upon the release question.

If, indeed, these mechanisms exist and affect release, then experimental and modeling techniques will have to be developed to aid in evaluating their importance. Based upon evidence now known, it is reasonable to assume the existence of a weakened basal layer condition. But there may be a number of disturbance types or imperfections which induce the triggering of the avalanche as the slope, by some process or other, reaches a critical stability state. If monitoring and control of the avalanche sensitivity of a slope is desired, then the important question is what physical changes occur early enough and with sufficient magnitude to reliably serve as a measure of slope stability. One possible macroscopic mechanism that may be detectable is local buckling of the slope. Evidence of long term large-amplitude buckling of snowpack is well documented, and the question arises whether buckling is a primary or secondary mechanism in avalanche release. Lacking conclusive experimental evidence of the importance of buckling, the concept is further explored in the remainder of this paper.

Material Representation for Buckling Analysis

The formulation of a possible buckling state is strongly dependent upon an adequate material characterization. To date an extensive variation exists in the constitutive properties used to study snow response. Most analyses are based upon linear constitutive equations, and time dependence expressed by a deformation or strain rate term (viscous response). In setting up a buckling model, it would appear that refinement in the constitutive law to account for more than one rate dependence can be treated. In constitutive law modeling to date, a linear viscoelastic model of low density snow has been reported by Shinojima (1967); however, in the absence of stress relaxation considerations, the model is based upon long-term fluid behavior. Results by Yosida (1966) and in tests conducted by the authors (Brown et al. 1972b), long-term solid material residual is observed, in that complete stress relaxation under constant deformation does not occur. An additional complication report by Shinojima (1967) is that the linear form of the constitutive equations is different for each type of loading investigated, which included simple tension, compression, and torsion. Thus, different material coefficients should be used depending upon local stress conditions. However, this form of material nonlinearity should not be a primary factor in formulating a buckling criterion. The existence of a weakened sublayer, which is generally recognized as a necessary condition for slope instability, results in incomplete stress transfer to the slope bed surface and a transmittal and intensification of bearing stress downslope. Thus, the toe region material is in a state of compression, which simplifies the requirements on the constitutive representation.

The nonlinearity noted by Shinojima (1967) in transition from a compression to a tension state is reflected also in his reported values of Poisson's ratio. In tension the Poissonic effect approaches that of an equivoluminal material, whereas in compression the Poissonic effect is small. This difference in material behavior under different types of loading is attributable to the skeleton crystal structure of snow, in which both volumetric and distortional deformation mechanisms act. This is markedly different from typical viscoelastic modeling assumptions, but should be accounted for in setting up a viscoelastic model of snow.

What is perhaps the greatest impediment to a simple constitutive representation of snow is the fact that snow behaves strongly nonlinearily to changes in deformation rates, loading sequences, etc. Yosida (1966) indicates a strong nonlinear relationship between normal stress and low strain rates in simple compression tests of snow columns. Application to analysis of buckling can be handled by equivalent linearization of the constitutive model in the standard method of treating material nonlinearity.

The behavior of snow is complicated by its dependence on a number of items, which includes temperature, density, and state of metamorphism. The state of metamorphism, as indicated by Yosida (1966) can be characterized in terms of the thermal history and stress history of the material. These considerations therefore make the complete thermomechanical characterization of snow an extremely difficult task to undertake. However, this approach of characterizing snow is probably not necessary for making a comprehensive analysis of the problem of buckle mode growth. It is quite possible, as indicated by Yosida (1966), that a large portion of the snow slab may be metamorphically stabilized during the months of January through March, and that the timewise variation of the material properties may be negligible. If this is the case, the material aging characteristics and thermal history effects may be neglected in formulating the material constitutive equations, which must necessarily be nonlinear. However, since the stress distribution in the downslope region of an imperfection zone in the slab is compressive, the use of equivalent linear constitutive equations can be considered a valid simplication. However, more research needs to be done to verify if this can be done. Some questions pertaining to this which must be answered are: first, the extent to which one simplified constitutive equation can be utilized to represent the entire slab (that is, the effect of density variation and the percentage of the slab which does stabilize metamorphically), and, second, the correlation between stabilization of metamorphosis and macroscopic material properties.

In summary, the key to the analytic treatment of the buckling question is a refined model of the constitutive representation coupled with simplifying assumptions on the range of parameters based upon the physical conditions of the slab buckling phenomonen.

Physical Characteristics of Snow Slab Buckling

Two buckling geometries can occur. One is buckling of the surface layer of the snowpack while supported by a bed surface cushion. This requires either an interstitial weak layer (as from water percolation or material stratification), or a metamorphized basal layer (as from formation of depth hoar). Perla (1971) determined from examination of a number of postavalanche slopes that in 65 percent of the cases depth hoar was in evidence. Admitting the mechanism of long-term buckling, the wave shape of a typical buckling mode induces local regions of bearing stress intensification on the basal layer of depth hoar. This overstress enhances the brittle fracture and collapse of the depth hoar matrix, and, thus, is a plausible mechanism as an initial triggering source.

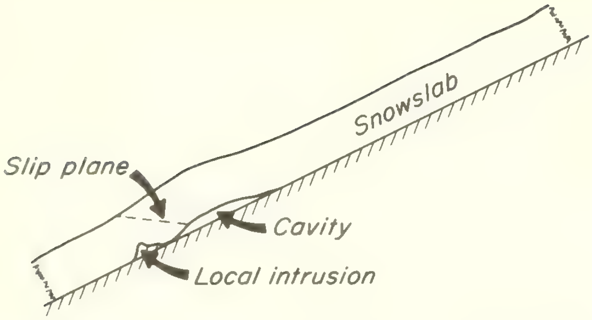

Figure 1. Geometric and stress intensification configuration due to local slab buckling.

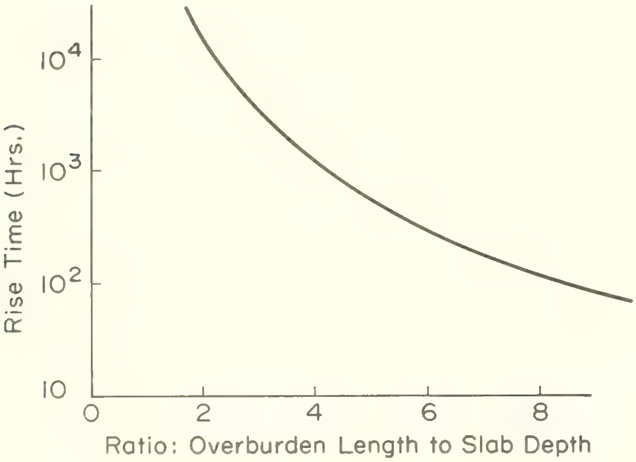

Figure 2. Rise time versus relative overburden length for specified initial imperfection amplitude to wave length ratio of 0.05.

The second buckling geometry is the formation of a buckling pattern of the entire slab, which implies cavity formation at the bed surface. Two alternatives exist here, that either the cavity exists and buckling follows, or that the tendency for buckling produces the cavity. Whichever is the case, the formation of a buckle lobe in the toe region produces a geometric and stress intensification configuration that enhances the formation of a slip plane (fig. 1). Alternately, the feasibility of a buckling mechanism "locking" a slope must also be examined.

To examine the question of whether or not buckle formation is physically possible in snow slabs, (1) snow columns were tested in compression, and (2) the material coefficients determined were used in a buckling analysis. Snow columns of nominal length 20 cm, and specific weight 0.39 gm/cm^3 were tested at -10° C at constant deformation rates up to 0.005 cm/min. The load-deformation data were fit by a linear three-element viscoelastic solid model, and a buckling analysis procedure was followed (Lang et al. 1973). Results of the computations are shown in figure 2. The interpretation is that for a given length of bed-surface imperfection having an initial amplitude 0.05 of its length, the curve shown is the boundary between growth and subsidence of the imperfection. The abscissa is the factor indicating the number of equivalent lengths of imperfection that must be bearing onto the imperfection zone to yield a corresponding rise time for an order-of-magnitude change in the amplitude of the imperfection. Thus, for an imperfection of length, ℓ, snow of equivalent length 4ℓ must bear onto the imperfection zone in order that the amplitude of imperfection increase by a factor of ten in 10^3 hrs or approximately 41 days. Thus, even though the snow specific weight is high and the test temperature is low for midalpine snowpack (both factors, if adjusted accordingly, decrease the time for amplitude growth), a reasonable estimate of a buckling mechanism is obtained.

To further define whether or not subsurface imperfections can form, a snow slope in the Bridger mountain range north of Bozeman, Montana, having a history of avalanche activity, was selected. A 40-meter-long trench was dug along the nominal 40° slope approximately one-third of the distance in from the left flank of the snowpack, which terminates into tree and rock outcrops on both flanks and at the crown. Void imperfections were found (fig. 3), which encompassed 40 percent of the 40-meter length. All voids were easily distinguishable, the largest having an amplitude of approximately 12 cm, and all voids extended under the snowpack indicating the exposed section probably was typical. Approximately 5 meters from the crown region tree outcrop a crack 20 meters in length and 0.3 meter in maximum separation ran parallel to the outcrop. The existence of this crack indicates that the particular slope was in a state of glide. However, the significant fact is that the void formation mechanism was more pronounced than snowpack settlement, which would cause subsidence of the voids. Thus, it is probable that slope creep rate relative to snowpack settlement rate is an important parameter on whether voids form or not. Once voids develop, any weakened subsurface condition that would result in incomplete shear stress transfer to the bed surface would reinforce void growth.

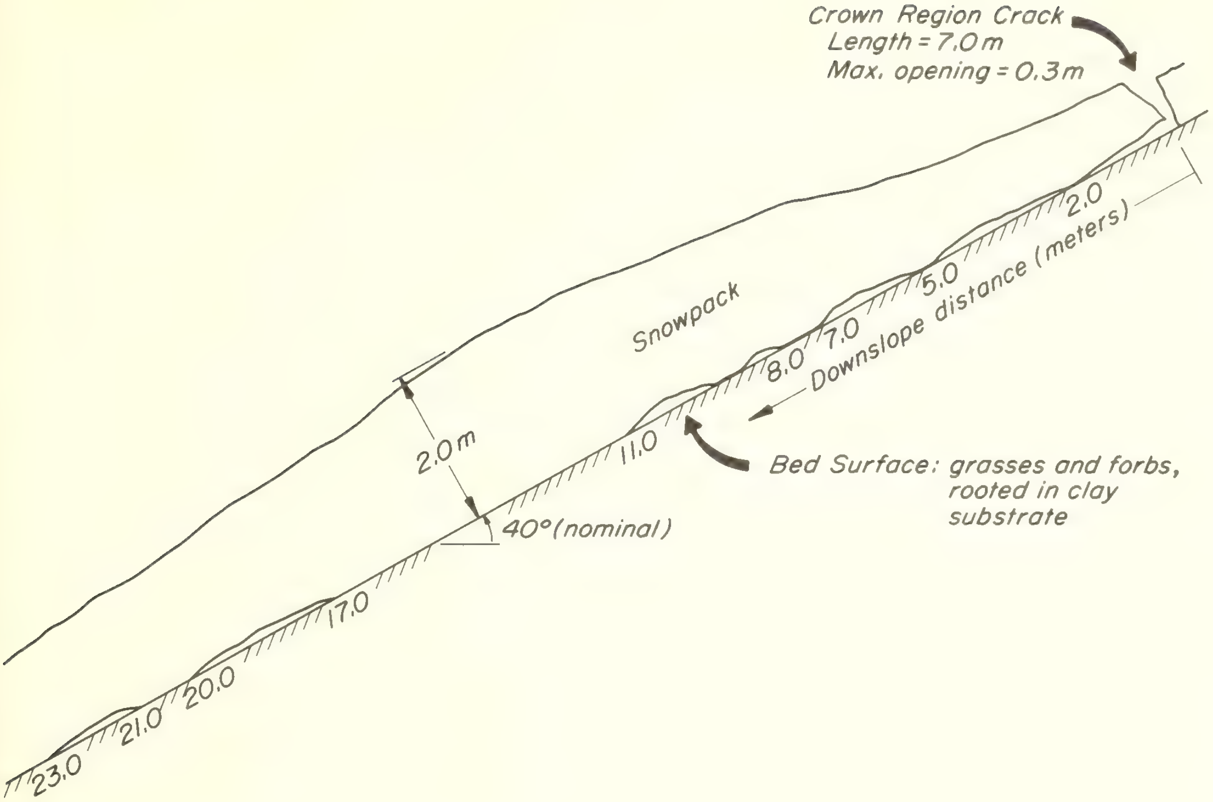

Figure 3. Slope cross section showing base lift-off, Bridger Range, Montana, January 19, 1972.

Final consideration is here given to a geometric profile described by Perla (1971). He indicates that the flank fracture profile of an avalanche zone has the shape of a sawtooth in a majority of cases. The sawtooth slants downslope, and conforms exactly to what would be predicted if a buckle wave with a downslope sagging central region were present immediately preceding avalanche release. Although the flank regions are influenced strongly by edge intrusions of rocks, trees, etc., if regular dimensions can be ascribed to the sawtooth pattern, this might relate directly to dominant buckling mode dimensions. Perla reports no data of this type, and the authors find none available in the literature.

Conclusion

Based upon the initial evidence concerning slab buckling, it appears that the possibility of a buckling state developing in avalanche-sensitive slopes must be considered. Using a simplified analytical model and nominal material properties, the times computed for buckle mode growth are at least of the same order as times associated with the avalanche phenomenon. The possibility exists for void formation and growth, depending upon the relative rates of snowpack settlement and slope-parallel creep, coupled with the necessity of a structurally weakened basal-plane zone. Also, evidence may exist on the flank region fracture profile that may correlate with dominant mode buckling pending further study and data acquisition.

Since buckling is a structural phenomenon extending into the toe region of the slope, physical measurement of void formation and buckle mode growth is difficult. Evidence of buckling from surface measurements is probably inconclusive because of wind transport of material that would obliterate long-term geometry changes. Thus, advanced *in situ* techniques such as acoustic emission monitoring, or slope modeling techniques, may be required to further assess the toe region influence on avalanche release.

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STATISTICAL PROBLEMS IN SNOW MECHANICS

R. A. Sommerfeld

ABSTRACT

Different types of statistical treatments are appropriate for evaluating measurements of different physical properties of snow. For density measurements, the mean and standard deviation of the measurements are meaningful parameters. In the case of strength measurements, the mean is not a very useful parameter, and some type of extreme-value statistics should be used. Weibull statistics appear to be appropriate for tensile strength data, while the thread bundle statistics of Daniels appear appropriate for the evaluation of shear strength data.

Introduction

Snow is a variable material; since most of its variations are random, statistical methods are indispensable in evaluating its behavior. Until recently, the statistical techniques applied to snow have been fairly simple. They have largely consisted of the calculation of the mean and sometimes of the standard deviation or confidence intervals of a series of measurements. Generally the measurements show such large scatter that attempts to correlate the various properties of snow have been frustrated.

Statistical techniques are available which can aid in a much better understanding of the behavior of snow and the relationships among its properties. It is necessary to use different kinds of statistical presentations, however, to extract the needed information from a series of experimental measurements. The appropriateness of a particular statistical technique depends on the properties being measured and the information desired from the measurements. As examples, we will examine statistical techniques which may be applied to density, brittle tensile strength, and shear strength data. Since the presence of free water in snow adds complications, this discussion will be limited to dry snow, although most of the concepts can be applied to wet snow as well.

None of the arguments presented are intended to be exhaustive. They are, rather, first attempts in this field; if they find application it will certainly be with extensive additions and modifications.

Snow Density

Dry snow is an intricate network of interconnecting ice crystals surrounded by air. The physical properties of ice and air are very different, and the volume ratio of ice to air can vary by over an order of magnitude. It seems obvious that the physical properties of snow must be related in very basic ways to the relative volumes of ice and air in a sample. The easiest measure of relative volumes is the density of the snow sample.

The variability of snow density is highest on a microscopic scale. If we were to proceed through a volume of snow taking 0.1 mm^3 samples at random, we would find some samples that were pure ice and some that were pure air. The data would range over values different by a factor of 10^3, but their mean value would be a measure of the bulk density of the total volume under consideration. Later we will see that this simple relationship between large and small samples does not hold for all of the properties of snow.

If consideration is restricted to density variations within major layers, the minor layering can be treated as statistical variations within the major layers. A careful study of the coefficients of variation within various sample volumes would answer the question of whether or not the densities of the major layers in an avalanche starting zone can be adequately determined from samples taken in a smaller volume. No study has been carried out with this approach in mind, but some data are available from other studies.

Martinelli (1971) measured the densities of 84 pairs of samples, each pair taken within a major layer. Each pair of $0.5 \times 10^{-3} m^3$ samples was taken in close proximity so that the variability between the members of each pair is a measure of the variability within sample volumes of about $2 \times 10^{-3} m^3$. The mean coefficient of variation between the samples was 3 percent. I have sampled approximately 1 m^3 volumes in 12 different snow layers using both $0.5 \times 10^{-3} m^3$ and $2.3 \times 10^{-3} m^3$ sample tubes. There was no difference between the results obtained with the different tubes, and the mean coefficient of variation was 10.8 percent. Leaf[1] found that, in volumes of 20 m^3, the coefficient of variation of water equivalent was 18 percent. Since the measurement of water equivalent includes both depth and density variations, we can conclude that the variability of snow density within a volume of tens of cubic meters is not much larger than the variability within a volume of 1 m^3.

Although the data are insufficient, it appears that samples taken from snowpits near avalanche starting zones will provide adequate measures of the densities of snow layers in the starting zones. It also appears that samples should be taken as widely spaced as possible within the pit to insure representative data.

Brittle Tensile Strength

There is an obvious relationship between the density of snow and its strength. Since the pores in snow cannot support any load, the entire load must be supported by the ice network. On a microscopic scale, tensile strength samples would range between zero, for air, and the maximum tensile strength of monocrystalline ice.

Unlike density, the tensile strength of a large volume of snow will not be the mean of a large number of random, microscopic subsamples. Problems arise in determining the distribution of stresses within a snow sample, but the major complication is that once part of the ice network fails, an increased load is thrown onto the remainder and the whole sample is very likely to fail. Thus, the strength of a large sample would not be the mean of the strengths distributed throughout the sample volume, but would be the minimum of the strengths distributed throughout the ice network. Put another way, we are of necessity sampling for an estimate of the minimum strength.

Suppose that the strength of a large volume ($\sim 1\ m^3$) of snow could be measured, then the volume broken up into smaller volumes ($\sim 10^{-3} m^3$) (without disturbing the distribution of strengths) and the strengths of the smaller volumes measured. The strength of the larger volume would not be the mean of the strengths of the smaller volumes, but would be the extreme low value found among them.

Cracks progagate through the entire slab thickness, which normally has a mean of about 1 m (Perla 1971). Stress gradients parallel to the slope are scaled to the slab thickness (Perla 1971, Smith 1972) so that a volume of about 1 m^3 seems to be the appropriate volume for strength considerations. Obviously, volumes of this size would be extremely difficult to test. We are then faced with the problem of determining the strengths of these large volumes of snow from smaller samples.

Fortunately, this problem is not unique to snow. A considerable amount of work has been done on strength problems of the type where there is a significant variation in the strengths distributed throughout a volume. The arguments given above are essentially those of Weibull (1939) who considered the general problem of the strength of nonuniform materials. Strength theories of this kind have the graphic name "weakest link" theories, apparently from the statement of Pierce (1926): "It is a truism, of which the mathematical implications are of no little interest, that the strength of a chain is that of its weakest link."

Weibull (1939) proposed the cumulative distribution function

$$F(\sigma) = 1 - e^{-V\left(\frac{\sigma-\sigma_u}{\sigma_o}\right)^m}, \quad \sigma \geq \sigma_u \qquad [1]$$

where σ is the applied stress, V the volume, and σ_u, σ_o, and m are material constants. This distribution is truncated in that the probability of failure at stresses below σ_u is zero.

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[1] Personal communication with Charles F. Leaf, Rocky Mountain Forest and Range Experiment Station, Fort Collins.

Snow is seriously weakened by large voids within snow layers, which appear to be formed during snow deposition. I have observed voids of approximately $10^3 mm^3$. Some measure of the size and frequency of these larger voids can be gained from a comparison of centrifugal tensile tests performed using two different sample diameters. Keeler and Weeks (1967), Keeler (1969), and Martinelli (1971) performed a total of 592 tests using a sample 60 mm in diameter. They reported that about 10 percent of their samples showed zero strength. Some of the zero strengths may have been due to sample damage, but some undoubtedly resulted when a void cut entirely across the specimen. In contrast I have performed 338 tests using 120 mm samples without observing any zero strengths (Sommerfeld and Wolfe 1972). Thus, voids above 100 to 150 mm in diameter are very rare or nonexistent within snow layers, supporting the idea that the strength distribution is truncated.

Although the voids probably act as stress concentrators in their vicinity, the stress is supported by the surrounding material. When a sample tube cuts a void, part or all of the surrounding material is left behind and a spuriously low strength is measured. Thus, we have the problem that the most important values are seriously disturbed by the sampling technique. Furthermore, the number of very low strength elements in a large volume is so low that we have no assurance we have sampled the lowest strength in a given volume unless we sample the entire volume.

An alternative method of predicting the strength of a large volume of snow comes from Weibull's distribution (equation 1). If all but the few lowest sample values of snow strength (which may be erroneous as discussed above) in a limited density range are fitted to Weibull's distribution, the constants and particularly σ_u can be determined. At very large V the function $F(\sigma)$ (equation 1) jumps from zero at $\sigma = \sigma_u$ to almost 1 at stresses just above σ_u. Thus, σ_u should be the large-volume strength. Figure 1 shows the theoretical infinite volume curve in comparison with an experimental curve obtained with sample volumes of $2.3 \times 10^{-3} m^3$.[2] It appears that a volume of $1\ m^3$ would fall very close to the infinite volume curve.

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[2] The reduced stress (σ/σ_m) used in this plot eliminates the effect of density differences among the samples (Sommerfeld 1971).

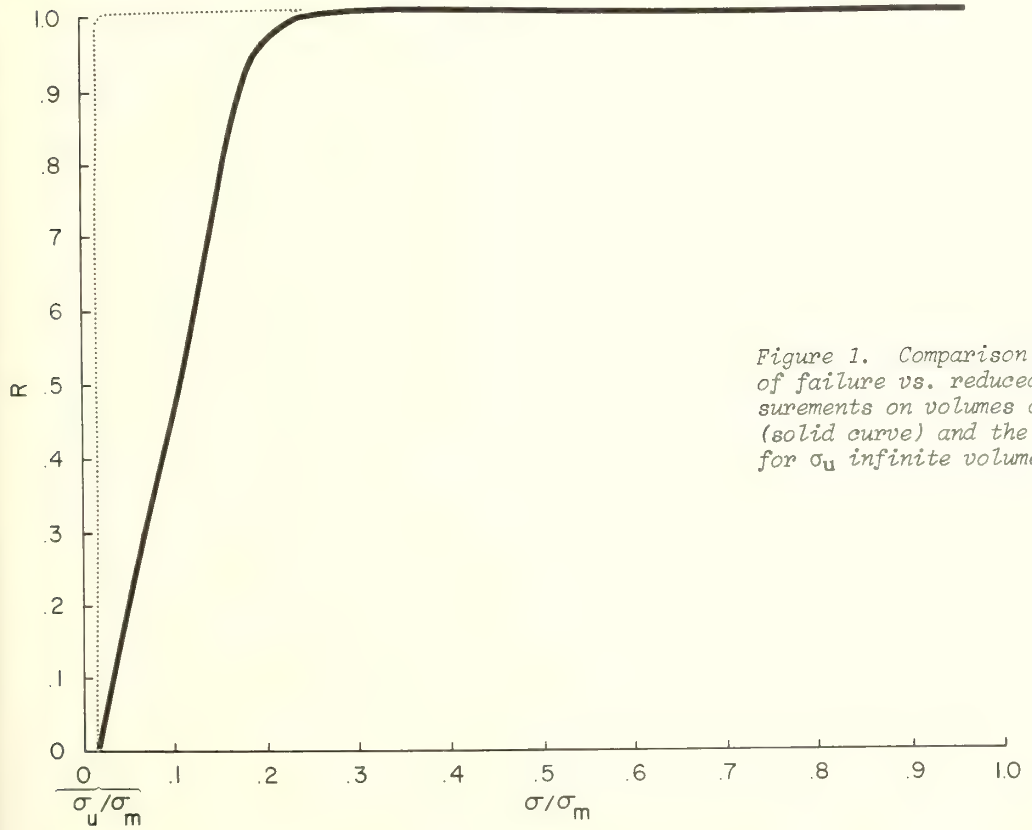

Figure 1. Comparison of the probability of failure vs. reduced stress for measurements on volumes of $2.3 \times 10^{-3} m^3$ (solid curve) and the theoretical curve for σ_u infinite volume.

To determine σ_u from centrifugal tensile tests, Weibull (1939) suggests the function

$$\ln \ln \frac{1}{1 - P} + \tfrac{1}{2} \ln \sigma = (m + \tfrac{1}{2}) \ln(\sigma - \sigma_u) + A(V) \qquad [2]$$

where P is the experimental probability of failure at stress σ and A(V) is a function of the sample volume. Equation 2 plots as a family of parallel curves, with different intercepts for different volumes. σ_u is determined as the unique value which gives the best fit to a straight line with $m + \frac{1}{2}$ as the slope.

Table I gives the calculated minimum strengths for various densities and types of snow. The snow was classified according to the scheme of Sommerfeld and LaChapelle (1970). Figure 2 shows σ_u plotted against mean density with the crystal type indicated at each point. In each case the lowest three strength values were discarded, since these values may be spuriously low, as previously discussed. In every case but the graupel (data group 11) the fit to the straight line was improved. In every case the fit to a straight line was very good, the lowest R^2 being 0.965 (fig. 3). A good fit to a straight line shows that the data fit the Weibull distribution very well. Of interest is the fact that the series which represents the normal course of equi-temperature metamorphism (1, 2, 4, 5, 6) falls on a very good straight line in figure 2. Because case 3 was somewhat windblown and 9 was heavily windblown, they might be expected to show higher strengths for their densities due to mechanical reworking. Cases 7 and 8 are dry, temperature-gradient (TG) snow and 10 is wet TG snow. Here we see that the strength of a TG layer can vary over a large range, which is supported by field observations. Graupel (11) gives a lower strength, which also agrees with the observations of Perla (1971).

TABLE I

DENSITIES AND CALCULATED MINIMUM STRENGTHS (σ_u)
FOR VARIOUS TYPES OF SNOW

Case Number	Snow Type	Ave. ρ Kgm^{-3}	σ_u dynes cm^{-2}
1	IA (Ple, Plf)	112	5.38×10^3
2	IIB2	254	14.24×10^3
3	IB (I 3aN2A)→IA1	128	9.53×10^3
4	IIA 1 - 2	147	9.32×10^3
5	IIA 1 - 2	228	14.15×10^3
6	IA (P2s)	73	4.12×10^3
7	IIIB3	281	15.58×10^3
8	IIIB 2 - 3	242	4.04×10^3
9	IB (I1)→IIB2	289	36.81×10^3
10	IIIB3→IVA1	331	20.69×10^3
11	IA (IR3b, 4a, 4b)	249	5.60×10^3

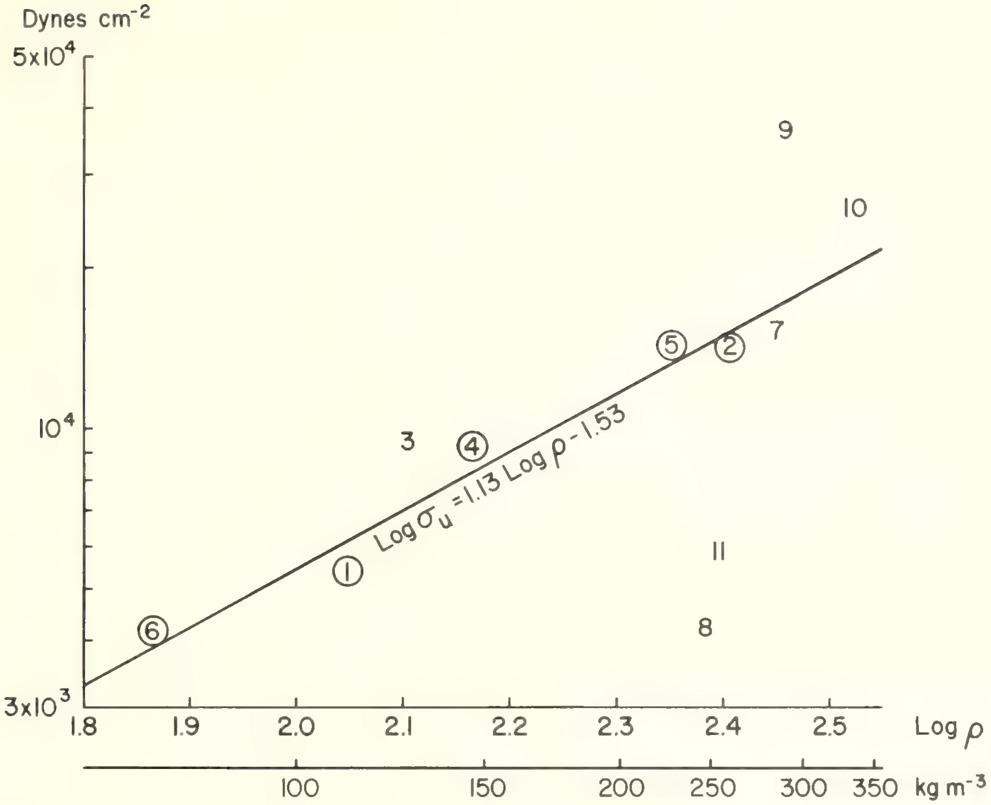

Figure 2. Calculated minimum strengths (σ_u) vs. density for various types of snow.

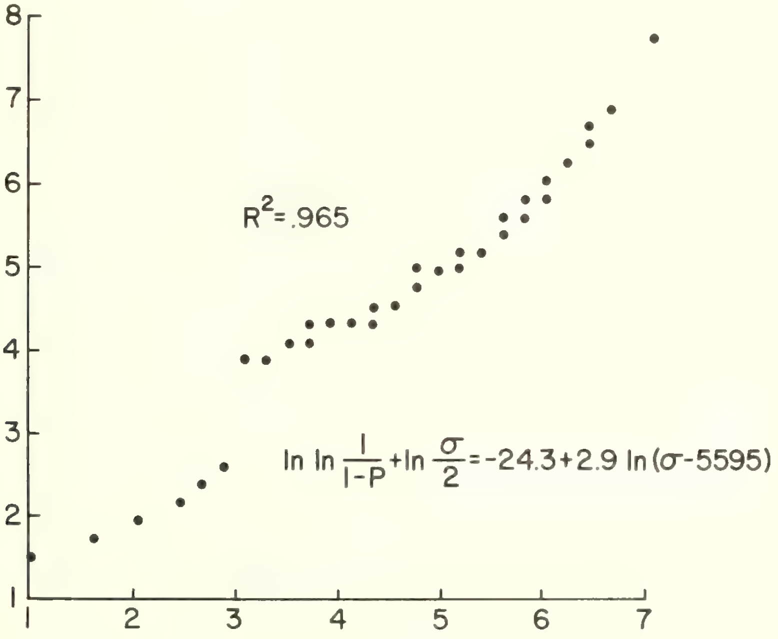

Figure 3. The worst fit of the data (case 11) to equation 2.

There are also similar but not so pronounced regularities exhibited by the other two constants. However, whatever meaning might be ascribed to such regularities is still a matter of conjecture.

Weibull's method as applied here boils down to assuming a distribution function (apparently chosen by Weibull for mathematical tractibility) that determines a set of constants from a set of data points, and uses the final function to extrapolate to an extreme limit. Undoubtedly such extrapolations are risky, but until data are available on the large-volume strengths of snow, this seems to be our only recourse. At least the Weibull analysis of the data leads to a fairly simple representation of the brittle tensile strength of snow, and that representation is consistent with other observations.

Shear Strength

Shear-strength measurements show characteristics similar to tensile-strength measurements (fig. 4). There is very large scatter in the data, but the measurements appear to fall between two extreme limits. Also, the larger the sample volume, the lower the mean of the measurements.[3] Here again the statistics of Weibull could be applied to determine σ_u for the shear strengths of various types of snow.

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[3] Personal communication with Ronald I. Perla, Rocky Mountain Forest and Range Experiment Station, Fort Collins.

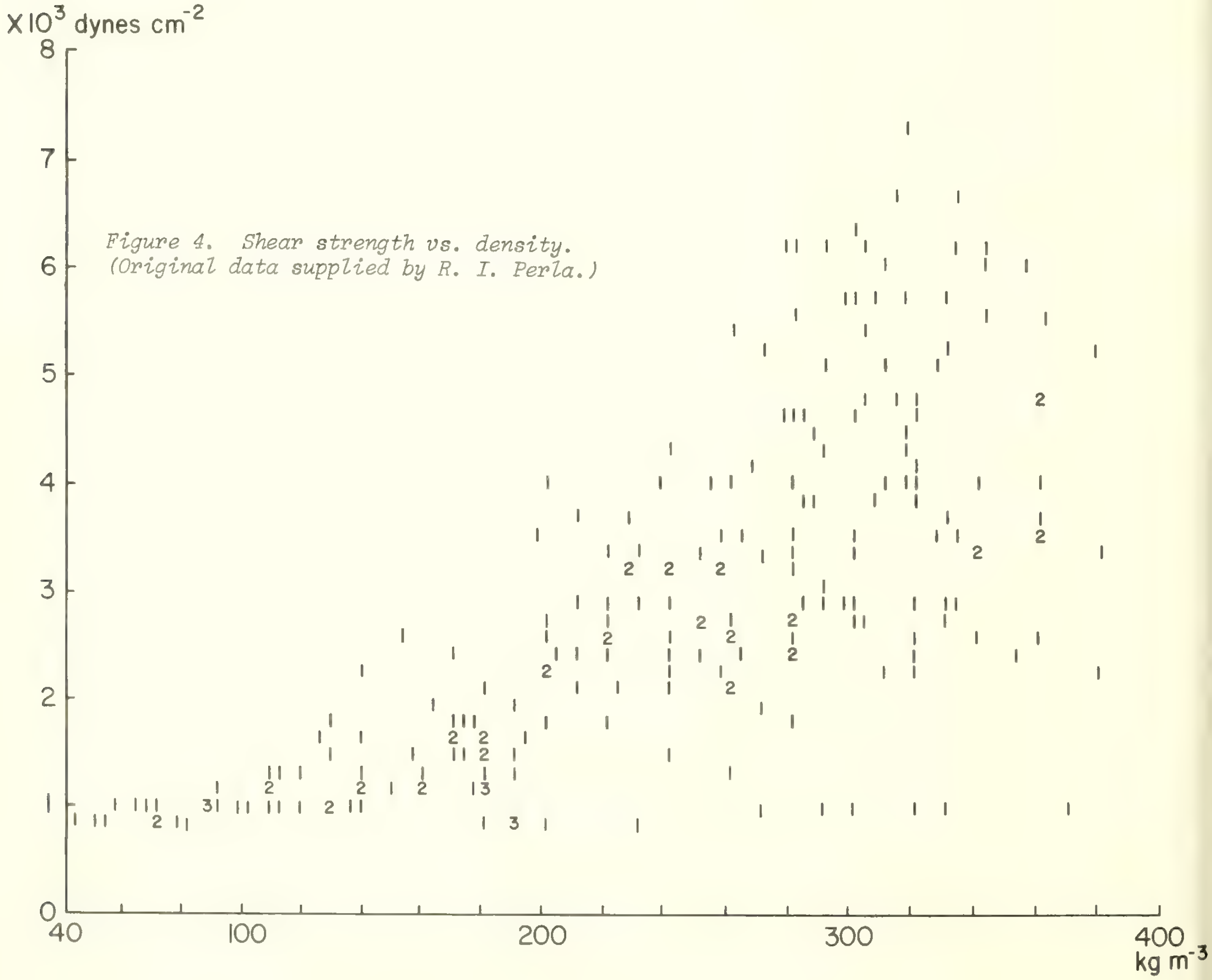

Figure 4. Shear strength vs. density. (Original data supplied by R. I. Perla.)

The assumption that avalanches are initiated by brittle shear crack propagation in the bed surface is open to question. During the formation of a tensile crack, the crack walls physically separate and the crack can become unstable and propagate in the manner of a Griffith (1921) failure. During shear failure, the failing parts are in contact, and friction and crack healing due to new bond formation impede crack growth. For these reasons a quasi-failure (Perla and LaChapelle 1970) is the likely initiating event. There is a strong possibility that a failure in a small part of the bed surface would not propagate elastically, and that the whole bed surface would not fail. Under such circumstances Weibull's statistics are not applicable, and the work of Daniels (1945), who considered the strengths of bundles of threads, appears to apply. Clearly the failure, at a particular stress, of one thread of a bundle may or may not lead to failure of the entire bundle depending on the strengths of the rest of the threads. Daniels showed that if $\theta(\sigma)$ is the probability density of the breaking stress (σ) of n elements, then a total load (S) is related to the load on each surviving thread (s) by

$$\frac{S}{n} = s \int_{s}^{\infty} \theta(\sigma)d\sigma \qquad [3]$$

and total failure occurs at the maximum

$$\frac{d\left[\frac{S}{n}\right]}{ds} = 0 = \frac{d}{ds} \left\{ s\int_{s}^{\infty} \theta(\sigma)d\sigma \right. \qquad [4]$$

s_T, the value of s at failure, can be found from the probability density function, and S_T/n, the stress at failure, can then be calculated.

The probability density function for snows of different densities can be derived from Perla's measurements.

The shear strengths measured by Perla for densities between 250 and 300 kg m^{-3} were found to fit the normal distribution with a mean of 30.0×10^3 dynes cm^{-2} and a standard deviation of 15.0×10^3 dynes cm^{-2}. Performing the calculations as in equations 3 and 4, we see that the failure stress for an entire layer within this density range, under our assumptions, is 15.8×10^3 dynes cm^{-2}, about 53 percent of the mean value.

Conclusions

The release of a slab avalanche is a complicated process. It appears that the initiation involves a volume of snow in the range 1 to 10 m^3. Field work indicates that it is necessary to interact with a volume of this size, with explosives, skiis, snowshoes, etc., to initiate an avalanche. Most slabs are about 1 m thick, and stress gradients parallel to the slope are scaled to the slab thickness, again indicating that a few cubic meters is the volume of interest for predicting slab failure.

Density is an important characteristic of snow slabs. The stresses within the slab are a direct result of the snow weight, and the mechanical properties of snow are related in basic ways to the snow density. Density is determined by the mean value of representative samples taken within a major layer. Available measurements are not conclusive, but do indicate that the density of 1 m^3 of snow in a major layer adequately represents the density of that layer.

The failure at the crown of a slab avalanche is undoubtedly brittle tensile fracture (Sommerfeld 1969), but the brittle tensile strength of snow cannot be understood in such simple terms as the density. The relationship of tensile strength to density is clarified by the application of "weakest link" strength theories. In particular, the statistics of Weibull (1939) give a consistent picture of the strength of a large volume of snow. It appears that the volume of interest in avalanche prediction (1 to 10 m^3) is large enough to be considered an infinite volume, and in that case the parameter σ_u in the Weibull distribution (equation 1) should be the snow strength. This strength has been shown to be a function of density for snows which have followed the normal course of equi-temperature metamorphism. Heavily windblown snow and temperature gradient snow need further study before their strength relationships become clear.

An important point which has been ignored in this study is the significance of the very large voids caused by rocks and vegetation which penetrate the slab. I know of no work on this subject, so at the moment nothing can be said concerning its importance.

The statistics of the shear strength of snow appear even more complicated. Since the failure of a part of the bed surface may or may not initiate the failure of the entire surface, the statistics developed for the evaluation of the strengths of thread bundles may be appropriate. In a limited test, measured shear strengths (in the density range 250 - 300 kg m^{-3}) were found to fit a normal distribution. Application of the statistics of Daniels (1945) for the large-volume case indicated that the bed surface should fail at about 53 percent of the mean shear strength of snow in that density range.

A complication which was ignored in the analysis is the time dependence of the shear strength of a snow layer. If a small part fails without initiating total failure, the snow in that part can rebond and the failure heal. This rate process might be included by making the shear strength distribution time dependent, but this has not been attempted.

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CONTROLLED RELEASE OF AVALANCHES BY EXPLOSIVES

Malcolm Mellor

ABSTRACT

The effects of explosives and blasting agents on snow are discussed from the viewpoint of rock-blasting technology. Air-blast, crater formation, and ground motion are considered, and the characteristics of various types of explosives are outlined. Recent developments in the commercial manufacture of liquid and slurried explosives and blasting agents are described, and the possibilities for application of these materials in avalanche control are explored.

Introduction

Explosives have long been used for deliberate controlled release of avalanches, using charge emplacement techniques that evolved to suit prevailing conditions. The principal methods of charge emplacement have been: i) hand delivery, in which solid charges are laid on the snow surface or thrust into the snowpack for immediate firing, and ii) projectile delivery, in which fuzed charges are fired into the target zone by guns. Consideration has been given to emplacement of explosive charges prior to winter for firing on demand, but this technique is probably unacceptable in areas where there is unrestricted public access.

Established methods appear to be reasonably effective, although from a technical standpoint there are some questionable aspects and quantitative information is very limited. From a safety standpoint, the record for avalanche blasting is very good, but safe application of traditional methods seems to depend heavily on the skill and integrity of control personnel; by contrast, industrial applications of explosives demand inherently safe procedures.

The following notes are intended to review the behavior of explosives and blasting agents, the response of snow to explosives, and recent developments that might be applicable to avalanche blasting. One objective of this review is to bring out the great difference in response characteristics between snow and the materials for which typical blasting technology has been developed.

Action of Explosives

An explosion involves very rapid generation of energy in limited space, with sudden development of great pressure, usually accompanied by violent gas expansion. It is commonly created by direct chemical reaction, but other thermal, mechanical, electrical, or nuclear processes can give rise to explosions when energy is released at rates greatly exceeding the local dissipation rate. In a chemical explosive a great amount of energy – approximately 1 kcal/g – is released in a very short time (microsecond reaction time), so that the power level is enormous (about 50 billion kilowatts per square meter at the detonation front).

Chemical explosives undergo exothermic reaction, propagating a reaction wave from the point of initiation. If the velocity of this wave is higher than the acoustic velocity of the unreacted material, as in "high" explosives, the process is called *detonation*; if it is lower than the acoustic velocity of the unreacted material, as in "low" explosives or propellants, it is called *deflagration*. Ideal detonation velocities of some explosives exceed 8000 m/sec. Detonation pressure (which can exceed 300,000 atmospheres in some explosives) is approximately proportional to the square of detonation velocity, and therefore explosives with high detonation velocity can be expected to produce intense shock waves and to have great shattering power, or brisance. By contrast, deflagrating explosives such as black powder are unlikely to transmit a true shock wave to surrounding material, and they depend almost entirely on gas expansion for their blasting effectiveness.

Gas blasting can also be accomplished with devices other than conventional chemical explosives. Air-blasting systems release high pressure air (typically around 12,000 lbf/in.^{2}) from containers charged by multi-stage compressors. Carbon dioxide systems vaporize liquid CO_2 by a heater element and discharge it from a shell at high pressure. Fuel/oxidant devices explode gas or vapor mixtures (e.g. propane and compressed air) in a combustion chamber and discharge through a venting port.

When fired inside a solid or fluid medium, a high explosive creates a severe stress wave, or shock wave, which initially propagates radially outward from the charge at a speed higher than the acoustic velocity of the medium. Geometrical spreading and losses in the medium cause the wave to attenuate rapidly, reducing both amplitude and velocity until it eventually becomes an elastic wave traveling at the sonic velocity of the medium. The initial amplitude of the shock wave from a typical high explosive far exceeds the yield strength of any solid material, and material in the immediate vicinity of the charge undergoes intense compression that is essentially hydrodynamic and adiabatic; brittle material such as rock is completely pulverized in this zone. As distance from the charge increases, plastic or inelastic compression becomes progressively less severe, and shear resistance of the confining material becomes increasingly important. At greater ranges, where wave amplitude drops below the elastic limit of the medium, tensile hoop stresses (tangential stresses) associated with the radial pressure pulse cause radial cracking. When the radial stress wave meets free boundaries (rock/air interfaces) at normal incidence it reflects as a tensile wave, and surface spalling will occur if the amplitude is great enough.

In many materials only a minor proportion of the total explosive energy is transmitted in the shock wave – typically less than 20% in common rocks, and sometimes only a few percent. For a given type of explosive, the initial shock intensity in a solid medium is governed largely by the efficiency of coupling between the explosive and the medium. Good coupling calls for intimate contact between the charge and the medium (as with a liquid or slurry explosive), and for "impedance matching," i.e. for the product of detonation velocity and density for the explosive to be approximately equal to the product of acoustic velocity and density for the medium. Once the shock has been transmitted to the medium, a great deal of its energy is absorbed immediately in the hydrodynamic compression zone. The effectiveness of a given material in transmitting or absorbing shock energy in the hydrodynamic zone is characterized largely by the Rankine-Hugoniot equation of state, or by a graphical "Hugoniot" characteristic giving the pressure/volume relationship for very rapid loading and unloading. In broad terms, a material that is highly compressible over the applicable pressure range can be expected to be effective in attenuating shock pressure.

The spherical wave propagating from a point charge in an isotropic infinite medium attenuates geometrically, with wave amplitude inversely proportional to radius and wave energy inversely proportional to radius squared. The wave also attenuates because of internal energy dissipation in the medium, with amplitude decreasing exponentially with distance traveled. The combined attenuation is best described by a function with an inverse proportionality factor and an exponential decay factor, but in practice it is usual to plot shock pressure against scaled radius on logarithmic scales and express the result approximately as a simple power relation, with amplitude inversely proportional to radius raised to a power of roughly 2 to 3, depending on the material type and the radius (the power decreases with increasing scaled radius).

So far the discussion has been confined to the stress wave, which actually accounts for only a minor portion of the explosive energy. It is next necessary to consider the expanding gases which follow the stress wave and contain most of the available energy.

All chemical explosives produce large volumes of high pressure gas, and in typical blasting situations most of the explosive energy is utilized in expanding this gas. In an underwater explosion the expanding gas produces a bubble which displaces water radially outward, continuing to grow until its internal pressure drops below the ambient hydrostatic pressure and flow reverses. (In deep water, the bubble pulsates in size, and it rises and deforms by buoyancy effects.) When an explosion occurs deep inside a solid medium, the gas can only expand into the cavity formed by shock wave crushing, into cracks formed by the shock wave, into pre-existing cracks or pores, or into cracks that are formed by the gas pressure itself. The usual objective in blasting practice is to create a situation where the expanding gas can form and exploit cracks so as to displace material to a free boundary.

Low explosives and gas blasting devices set deep into strong impermeable material are often incapable of initiating cracks; they have to rely on existing flaws such as cracks, pores, planes of weakness, etc. However, they are particularly effective in situations where shock damage is either unnecessary or detrimental. For example, in blasting hard coal there is no necessity for stress wave shattering, and in "heaving" surface slabs, such as concrete pavements or floating ice, shock damage can produce premature venting of the gas, with consequent reduction of flexural breakage. For blasting strong uncracked rock in large masses it is usually more economical to use a high explosive, using the shock wave to initiate cracks that can be exploited and extended by the gases. For any type of explosive an air space between the charge and the solid medium can greatly reduce the initial gas pressure as well as shock wave amplitude, and an unstemmed shothole can similarly reduce the gas pressure that is applied to the blasted material.

In order to characterize the properties of explosives and the blast response of materials, it is convenient to scale shock and blast effects to remove the effect of charge size. In ordinary blasting practice, where body forces in the blasted medium are negligible, dynamic and geometric similitude permits linear dimensions such as charge depth, burden, hole spacing, crater radius, etc. to be normalized with respect to charge radius for a given type of explosive. For a given charge density the charge volume is proportional to charge weight, and thus it has become usual to scale linear dimensions with respect to the cube root of charge weight, i.e. a length measured in feet is divided by the cube root of charge weight measured in pounds to give a scaled length expressed in units of ft/lb $^{1/3}$.

Response of Snow to Explosives

Snow is very different from materials that are usually blasted by explosives; it is very weak, and can be excavated and handled with ease. However, the low strength and low density of snow do not lead to any great increase in blasting effectiveness, since snow is an energy-absorbing medium.

The coupling between a high explosive charge and snow is generally poor, and theoretically the impedance matching is far from ideal. The snow lying in avalanche starting zones is not likely to have acoustic velocities much above 1000 m/sec, and low density snow may have acoustic velocities of only a few hundred meters per second. Thus the product of acoustic velocity and snow density is likely to be an order of magnitude lower than the product of detonation velocity and density for explosives and blasting agents. By contrast, the impedance matching ratio for frozen soil is close to unity for typical explosives. In snow the hydrodynamic zone, in which energy is absorbed by inelastic compression of the material, is relatively large, as snow is readily compressible and a significant amount of compression is irreversible. Adiabatic compressibility curves (Hugoniot curves) show that snow of about 0.4 g/cm^3 density can be compressed to about 50% of its unstrained volume by pressures of only 20 bars or so.

Direct experimental evidence shows that dense snow, of the type found in the surface layers of the Greenland Ice Sheet, is tremendously effective in attenuating stress waves (Fig. 1). At close range, such as 1 ft from a 1-lb charge, the peak pressure in snow is much smaller than the

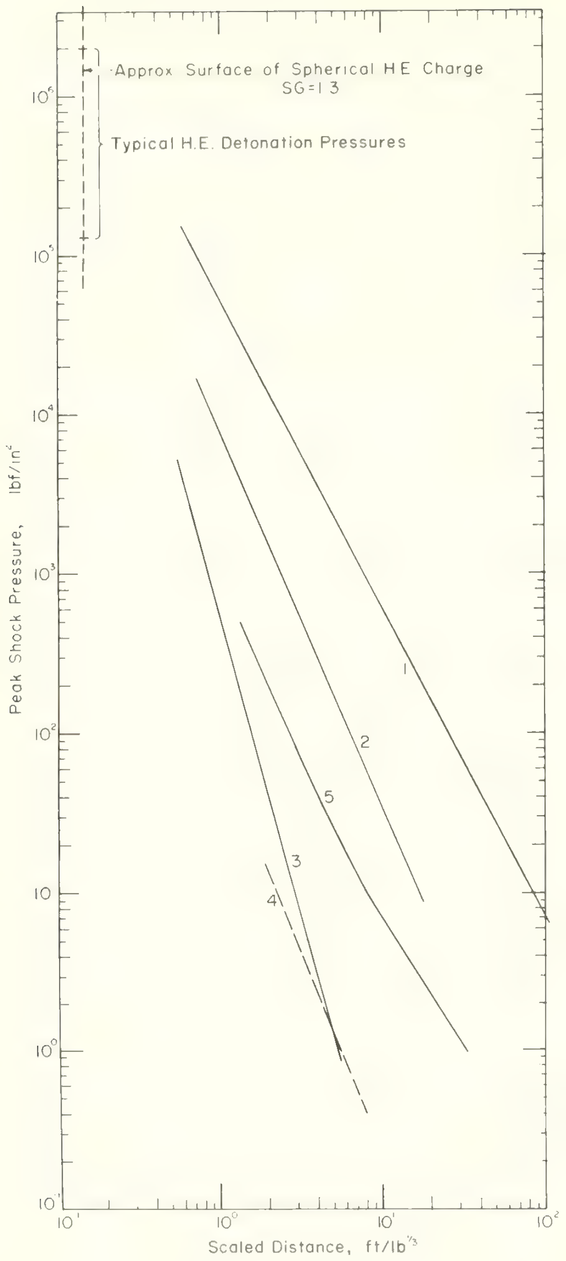

Figure 1. Stress wave attenuation in various materials. 1) Granite, 2) glacier ice, 3) ice cap snow, 4) seasonal snow, 5) air. (See Mellor 1968 and 1972 for details of data sources.)

corresponding pressure in granite – about 100 times smaller. Looking at the attenuation in relative terms, the scaled distance from the charge at which shock pressure drops below the uniaxial compressive strength of the material is shorter for snow than for granite.

The strong attenuating properties of snow become evident when explosive cratering capabilities are considered. In Figure 2 the dimensions of craters in dense snow are plotted against charge depth, all linear dimensions being scaled with respect to the cube root of charge weight. Comparative data for solid ice and frozen ground are given in Appendix A. In spite of the low density and low strength of snow, crater dimensions are very similar to corresponding dimensions for solid ice, and crater radius in snow is about the same as crater radius in frozen soils.

When a concentrated explosive charge is detonated in air above a snow surface a pressure wave propagates spherically, eventually making contact with the surface and reflecting from the surface. Reflection reinforces the pressure wave, but a snow surface is less effective than a rigid surface in producing this reinforcement. Figure 3 gives relationships between incident pressure and reflected pressure at normal incidence for a snow surface and a rigid surface. The reflected wave travels through air that has been compressed adiabatically by the incident wave, and since this allows it to travel faster than the incident wave it can overtake and fuse with the incident wave for a certain range of incidence angles, as illustrated in Figure 4. This effect causes the airblast pressure at the snow surface to vary with distance and with height of burst as shown in Figure 5.

Release of Avalanches by Explosives

The exact mechanism by which explosions release avalanches is not known, but some relevant factors can be identified.

First of all, an explosion propagates a stress wave that can travel through the air above the snow, through the snow itself, or through the ground beneath the snow. The stress wave abruptly displaces particles in the material it traverses, producing strains and accelerations. Secondly, the explosion generates a bubble of rapidly expanding gas that can thrust against confining material and can pressurize cracks and pores.

The general aim is to destroy the stability of an inclined layer of snow by increasing stress, by decreasing strength, or by a combination of the two.

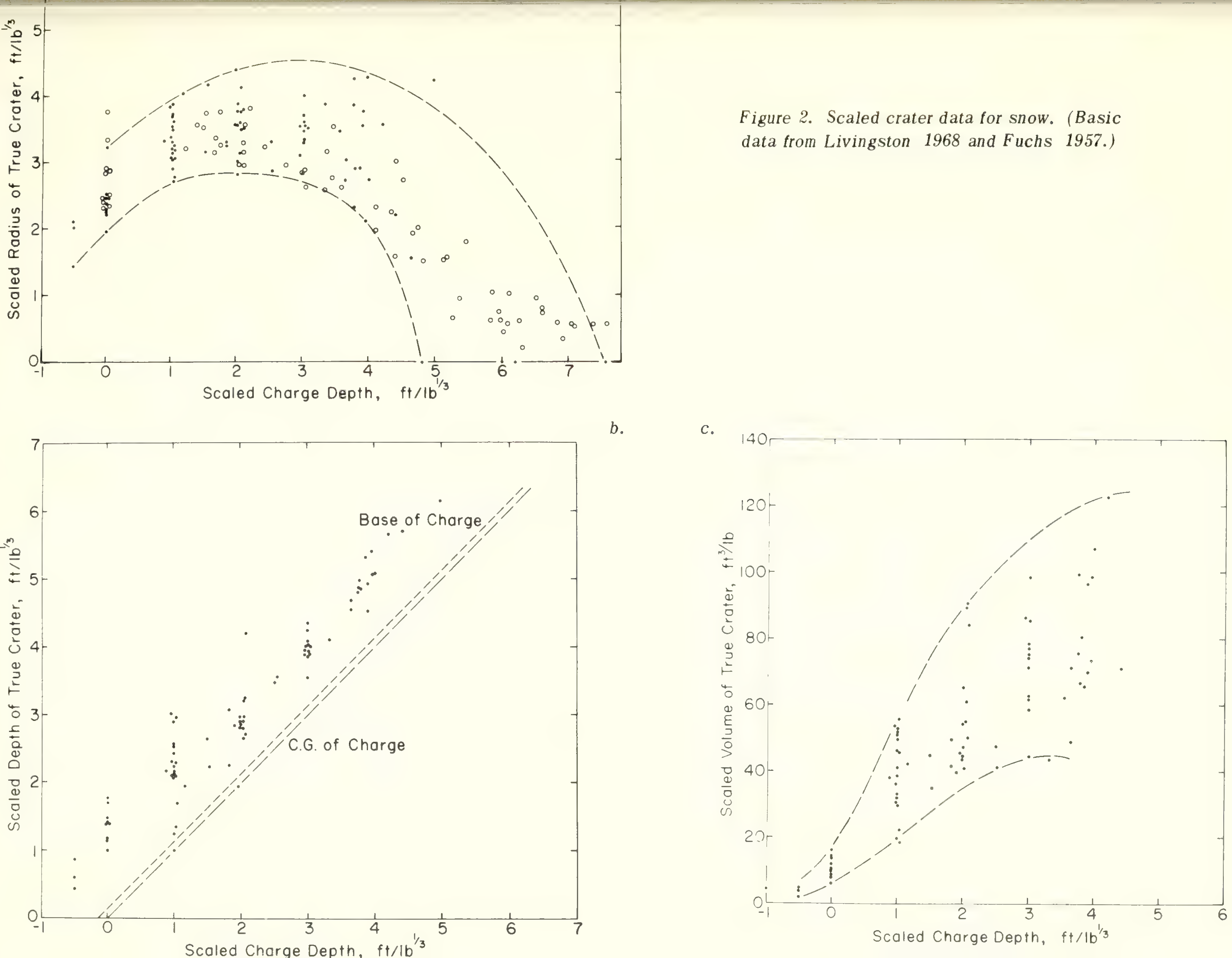

Figure 2. Scaled crater data for snow. (Basic data from Livingston 1968 and Fuchs 1957.)

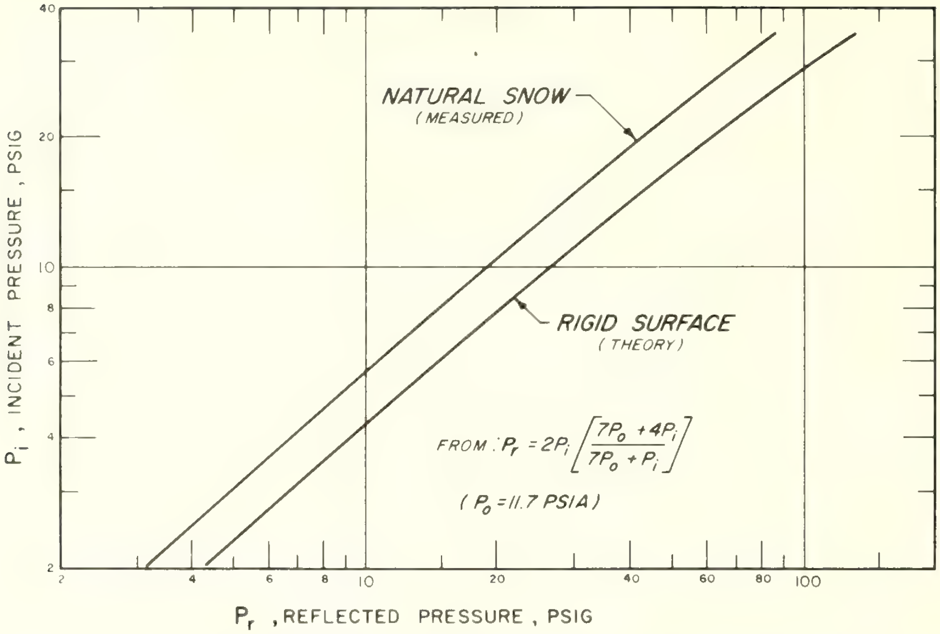

Figure 3. Relations between incident pressure and reflected pressure for normal reflection of airblast from a rigid surface and a snow surface. (From Ingram 1962.)

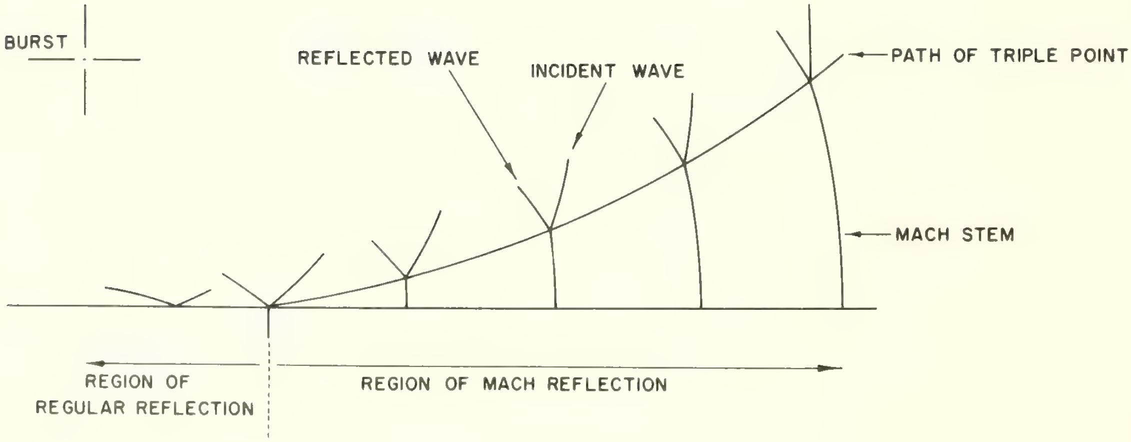

Figure 4. Wave fusion and mach front progression for airblast over a reflecting surface.

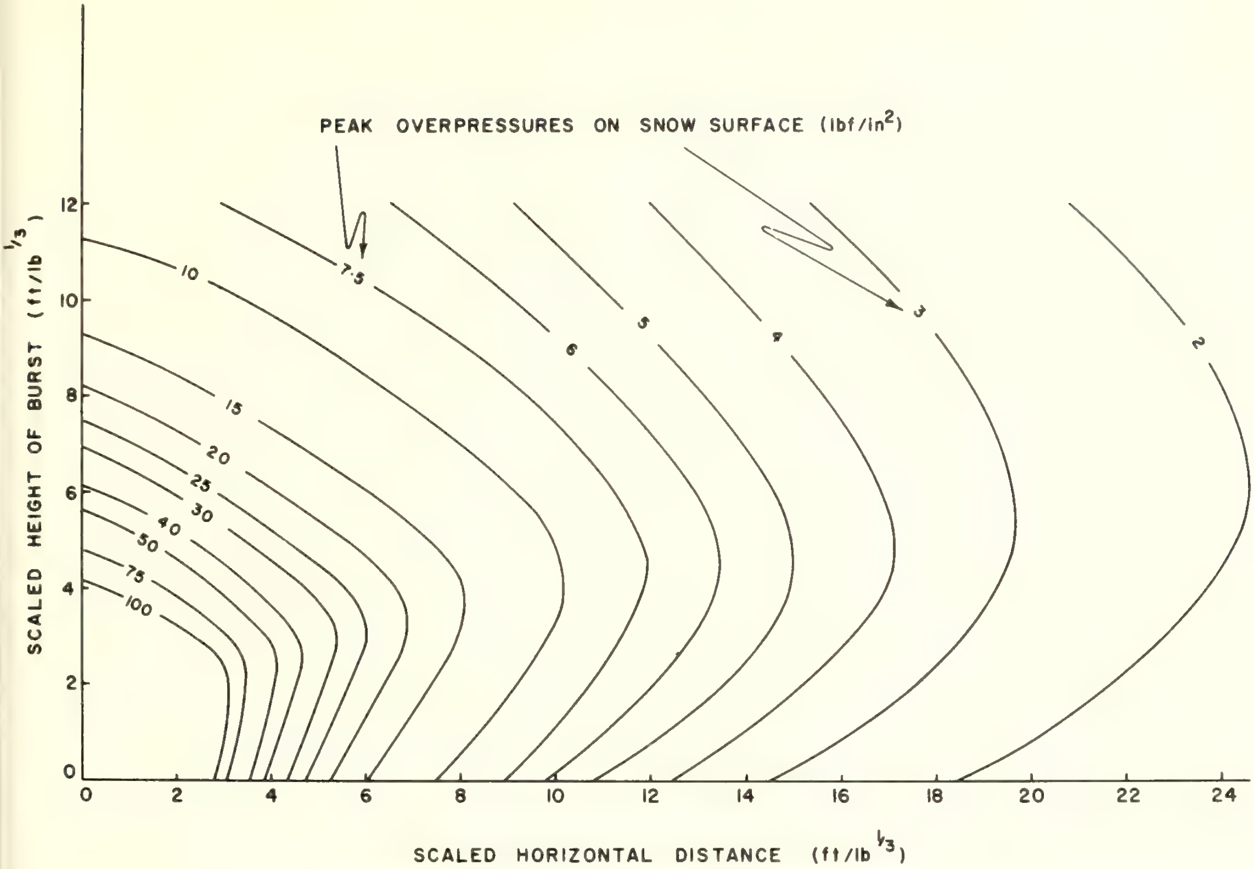

Figure 5. Peak overpressures related to height of burst and distance from ground zero for airblast over snow. (After Ingram 1962.)

One very positive method of attacking the snow slope, especially when it consists of a coherent slab, is to cut a swath in a direction normal to the fall line, thereby interrupting the continuity and at the same time applying downslope thrust, airblast, ground shock, and ejecta impact. This approach calls for either a line of point charges or a continuous linear charge, and there is no doubt that the charges should be set at optimum depth, which for practical purposes can be taken conservatively as 3 ft/lb$^{1/3}$ (striking a balance between maxima for crater radius and crater volume and allowing for variation of snow type). In practice, charges would probably be set within about 1 ft of the base of the snowpack, and optimum charge weight W_{opt} (lb) would be calculated for the actual overburden depth H (ft) using the relationship $W_{\text{opt}} = (H/3)^3$. A simple rule for estimating spacing of point charges would be to take spacing equal to twice the charge depth. This method is positive, but it is not economical and in many cases would amount to overkill.

A very different method is to apply airblast to the snow surface, thereby creating a brief (~ 10 msec) increase of normal stress and downslope shear stress. With this method much of the explosive energy is dissipated in air, but the loading is relatively widespread. A quantitative approach to airblast loading is difficult, since the release mechanism is not fully understood and the required overpressure varies considerably with the type of snow and its inherent stability. A simple way of looking at the problem is to consider the airblast as a transient normal pressure which at distant range translates to an increase of downslope shear stress and an increase of intergranular friction, the latter effect being partly offset by pressure rise in the pores of the snow (pressure rise in the pores lags and attenuates with increasing distance from the surface). Some indication of a lower limit of useful airblast overpressure is provided by sonic booms from aircraft, which sometimes release unstable snow with widespread overpressures of approximately 2 lbf/ft^2 (1.4×10^{-2} lbf/in.^{2}).

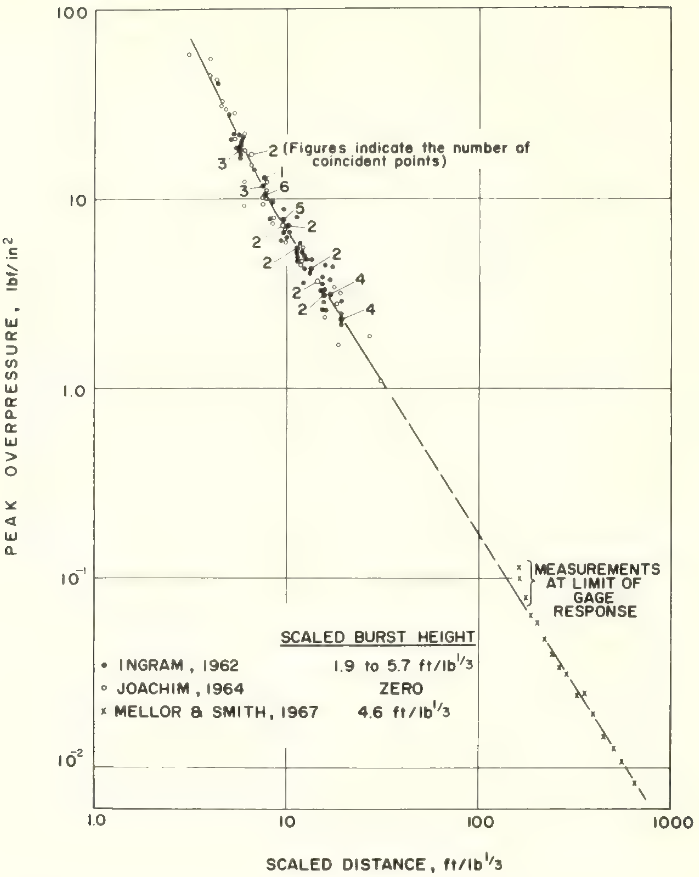

Figure 6. Airblast overpressure above a level snow surface (all data adjusted to 6000 ft altitude).

This pressure level is equivalent to rapid addition and removal of 4 to 5 in. of low density (0.1 g/cm^3) snow at typical release zone slope angles. For more positive results from airblast it might be better to plan on covering the target zone with at least 0.5 lbf/in.^{2}, which is rather higher than the nominal ground pressure of a man on skis. With a burst height of about 5 ft/lb$^{1/3}$, pressures exceeding 0.5 lbf/in.^{2} would spread to a radius of almost 50 ft/lb$^{1/3}$ (Fig. 6), i.e. a 1-lb charge fired about 5 ft above the snow surface would cover a target zone 100 ft in diameter, or an 8-lb charge fired at a height of about 10 ft would cover a 200-ft-diameter zone. With a charge fired at the snow surface, the coverage radius might be about 25% lower than the values given, but the charge will also form an appreciable crater (Fig. 2).

A third possibility is to fire charges at the base of the snowpack, using the underlying ground to spread the shock and limiting charge size so as to suppress venting and thereby utilize gas expansion within the snow cover. One potential advantage of this technique is that shock attenuation in rock is much less than in snow or air (Fig. 1), so that ground disturbance ought to be significant over a relatively wide area. The other feature is that gas expansion can be used to exploit planes of weakness and to pressurize the pores of the snow, the aim being to "heave" the snowpack and to lower the shear strength by increasing pore pressure. With this method, charges would be laid in contact with the ground and charge size would be scaled to give critical weight W_{crit} (lb) for the prevailing overburden H (ft) using the relationship $W_{crit} = (H/7)^3$.

Possibilities for Technical Developments

There are a number of possibilities for innovation in avalanche blasting, but it would be desirable to first make a systematic study of the relative effectiveness of airblast, hydrodynamic disruption, undersnow shock, undersnow gas expansion, and ground shock. Without such information, it is difficult to assess various types of explosives and blasting devices, or to select optimum methods of charge emplacement or projectile fuzing. However, it may be worth mentioning some techniques that do not seem to have been tested for avalanche blasting.

Over the past decade there have been considerable developments in the production and use of explosives and blasting agents based on ammonium nitrate, particularly in slurry form, and there has been renewed interest in liquid explosives, especially those based on nitroparaffins and hydrazines. Some of these materials are blasting agents that contain no high explosive ingredients and are not cap-sensitive, while other materials consist of two separate non-explosive components that are blended into an explosive immediately before use. These characteristics permit the materials to be transported, handled and stored under more relaxed regulations than those that cover Class A explosives.

The availability of cheap and safe fluid explosives opens up some prospects for novel applications and emplacement techniques in avalanche work. For example, plastic pipes could be laid from a safe and sheltered standpoint to an avalance release zone before the first snowfall, and fluid explosive could be loaded hydraulically as required during the winter, using gravity flow or pumping. The blasting cap for each pipeline could be either pre-placed or in the charge chamber introduced with the hydraulic load. The charge chamber could be designed to give a concentrated charge, a linear charge, or a dispersed charge, and it could be set either at ground level or at the top of a post rising above snow level.

At places where frequent repetitive avalanche blasting is required in a limited area, such as at a mine site in the mountains, a permanent installation of compressed air blasting equipment might have operational and economic advantages. With this type of system reusable airblasting shells would be set at ground level in avalanche release zones, with high pressure lines running to a centrally located multi-stage compressor. The shells would fire automatically by remote control when a pre-set pressure level (around 12,000 lbf/in.^{2}) was imposed by the compressor. The blasting elements installed on the snow slopes would be completely inert until activated by the controller. Initial cost of such a system would be relatively high, but operating costs would be low.

The technical effectiveness of gas blasting could be tested easily and cheaply by using carbon dioxide shells, which themselves could be used as a substitute for explosives in a pre-placement system. These shells contain liquid carbon dioxide, which is vaporized and discharged when an electrically actuated heater element is fired.

There are possibilities for development of a cheaper system of repetitive blasting using direct combustion of gaseous fuel/oxidant mixtures such as propane and ordinary compressed air. A system of this type would probably have a combustion chamber permanently installed at the blasting site, with rechargeable storage tanks for fuel and oxidant nearby. The chamber would be charged for each firing by remotely operated valves, and would be fired electrically with a "spark plug."

Permanent installations for avalanche blasting can probably not be justified in most areas under present conditions, but it seems quite likely that increasing recreational and industrial activity in the mountains could change the situation in the future. Pushbutton systems would be less entertaining than hand-charging or artillery fire, but they might be safer and more positive.

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Appendix A. Crater Data for Ice and Frozen Ground

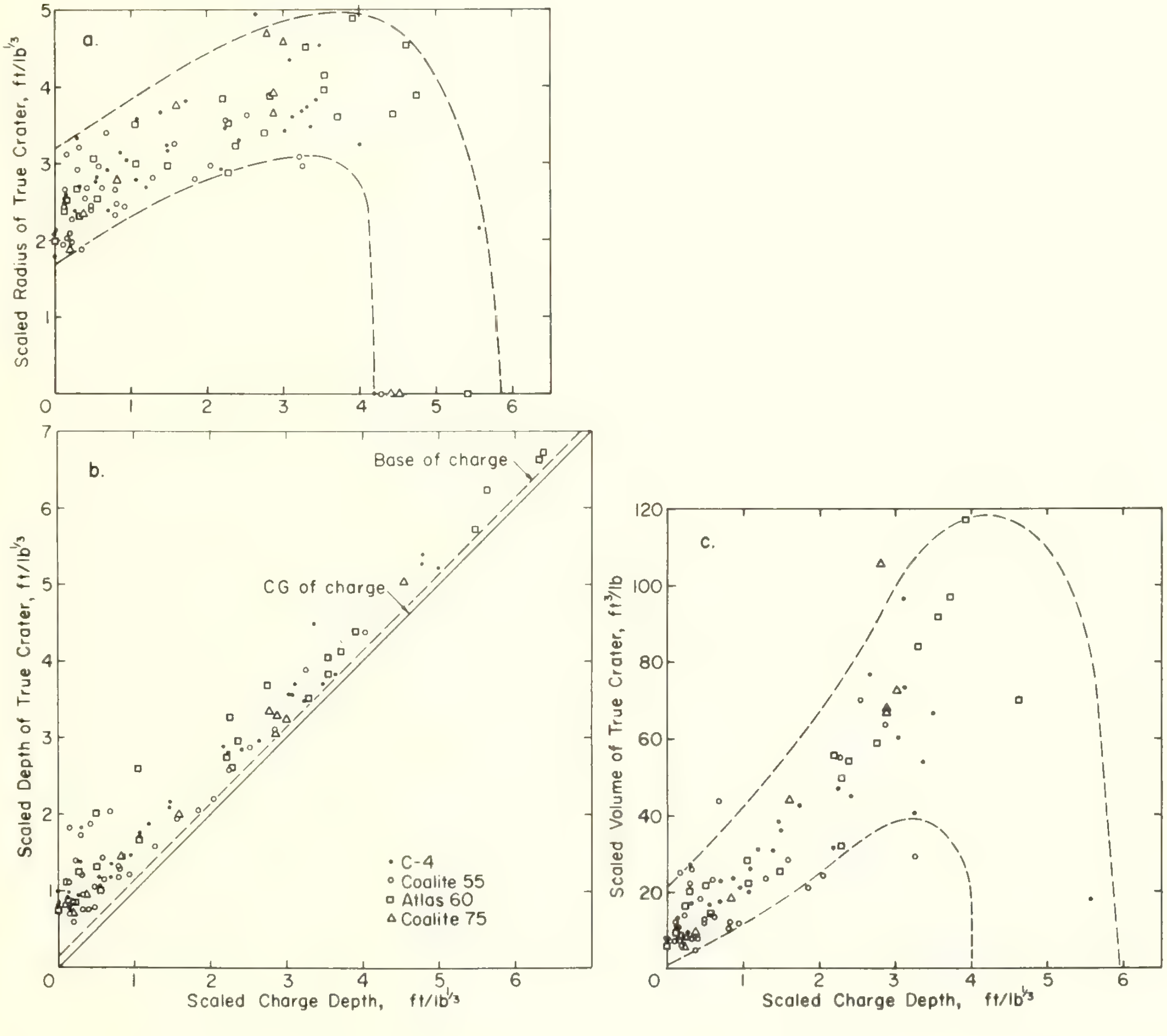

Figure A1. Scaled data for cratering blasts in massive glacier ice. (Scaled from test results by Livingston 1960.)

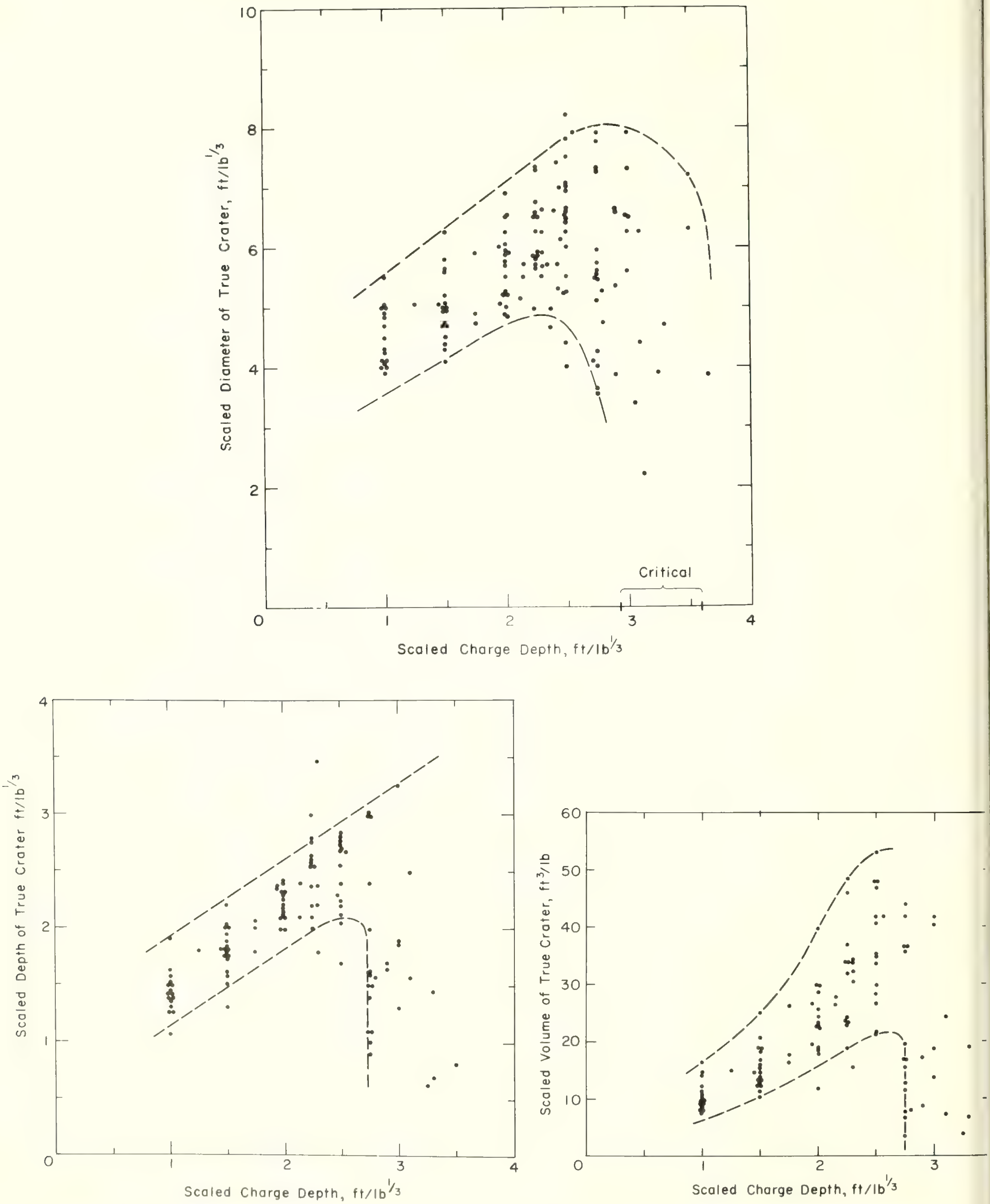

Figure A2. Scaled crater data for frozen silt. (Basic data from McCoy 1965, Mellor and Sellmann 1970, Mellor 1971.)

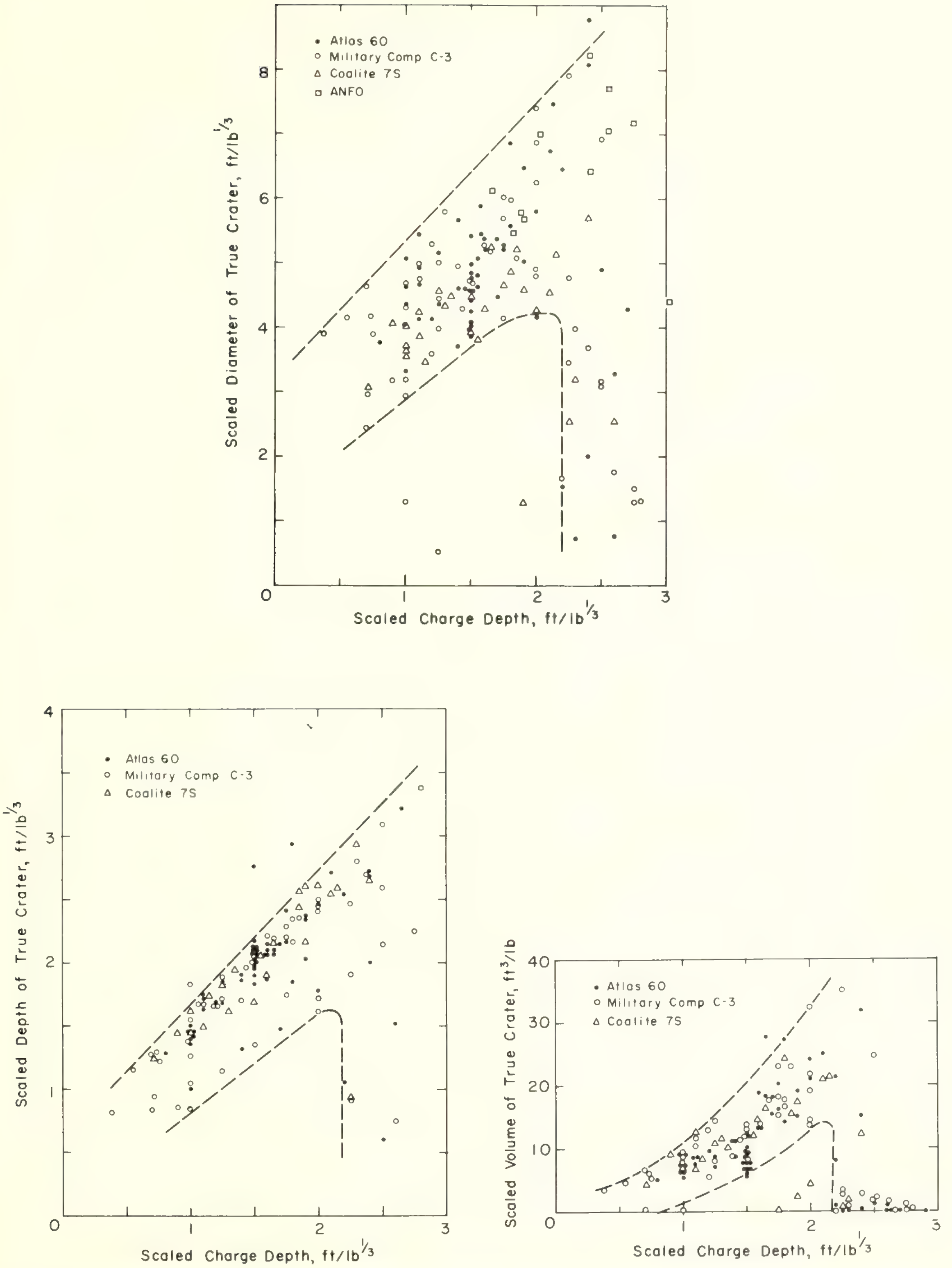

Figure A3. Scaled crater data for a frozen mixture of gravel and silt. (Basic data from Livingston and Murphy 1959, Mellor and Sellmann 1970.)

OBSERVATIONS OF AVALANCHE IMPACT PRESSURES[1]

P. A. Schaerer

ABSTRACT

Observations were made of impact pressures produced by well developed dry snow avalanches. The equipment is described and preliminary results of two years observations are summarized. There is a strong variation of pressure during the passage of an avalanche. The peak pressure, p, observed several times in one avalanche, can be expressed as $p = \rho v^2/2$ with v the apparent speed of the avalanche front and ρ the density of the deposited avalanche snow. The average pressure was found to be 0.3 p.

Introduction

Impact pressures due to snow avalanches influence the design of structures such as bridges and towers of powerlines, which are located in their potential path. The Division of Building Research of the National Research Council of Canada initiated observations of impact pressures with the objective of obtaining information concerning the characteristics of avalanches and the loads produced by them on structures. Studies were carried out at Rogers Pass, British Columbia, where numerous avalanche paths are easily accessible from the Trans Canada Highway.

Observation Site and Equipment

An avalanche path was selected where more than 10 avalanches occur every winter. The avalanches originate 2,100 m above sea level and fall over steep rock and a snow-filled gully to the observation site at 1,330 m. For 200 m above the measuring site, the avalanche track is a straight channel with an average incline of 33°.

Several load cells were mounted on a steel frame in the center of the track (fig. 1). The cells had a surface area of 645 mm^2 (1 $inch^2$). They were placed in cylindrical, streamlined steel holders, which, in turn, were mounted on a steel vertical beam. The beam had a width of 50.8 mm (2 in.) and so was a minor obstruction to the moving snow. Impact pressures were measured with strain transducers and recorded on a light beam oscillograph at a sheltered location.

Numerous difficulties and failures of equipment had to be overcome during the first 3 years before reliable observations were obtained. Between 1970 and 1972, however, impact pressures produced by several dry snow avalanches were recorded.

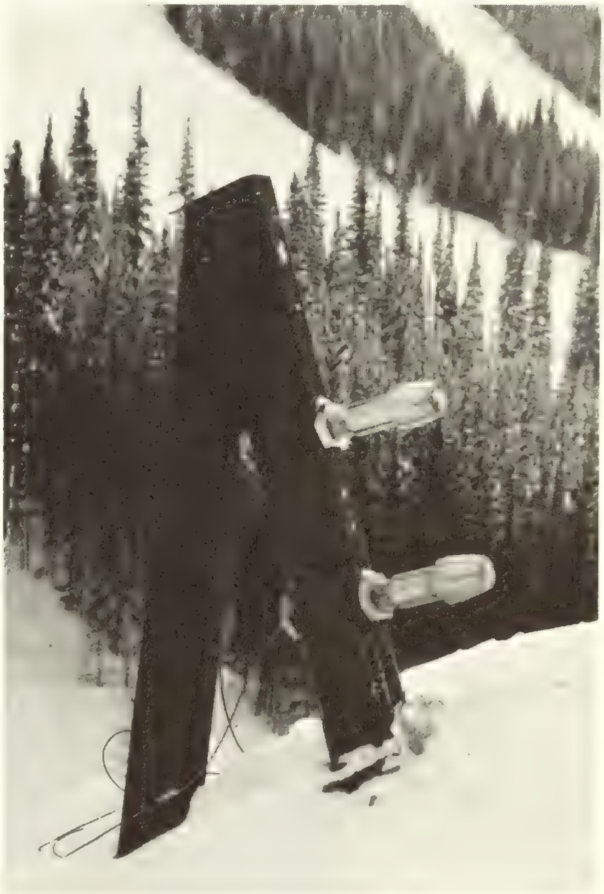

Figure 1.--Steel frame with two load cells.

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[1] This paper is a contribution of the Division of Building Research of the National Research Council of Canada, and is published with the approval of the Director.

Characteristics of a Dry Snow Avalanche

Dry snow avalanches become a mixture of flowing and airborne powder snow when falling over steep and irregular terrain. Visual observations of moving and deposited avalanche snow indicated that the flowing part consists of an aggregate of particles that range between powder of size 0.1 mm to balls about 100 mm in diameter. The depth of the flowing snow could be estimated from traces on the side of gullies and from the height to which snow was pressed against tree trunks in avalanche tracks. Numerous observations of this depth were made in the Rogers Pass area, and it was found to be usually three to four times greater than that of avalanche snow after it came to rest. The bulk density of the flowing snow, therefore, can be assumed to be about 0.3 times the density of the deposited snow.

The speed of the avalanche was determined by timing the avalanche front as it moved over a known distance in front of the load cells. The speed of the avalanche front may not be equal to that of the flowing snow behind the front, but it was the only speed observation that was practical.

Recorded Impact Pressures

The number of pressure cells was limited and allowed the observation of the impact pressure of the dense, flowing part of the avalanche only to a height of about half its depth. Figure 2 shows the pressures observed during the passage of an avalanche.

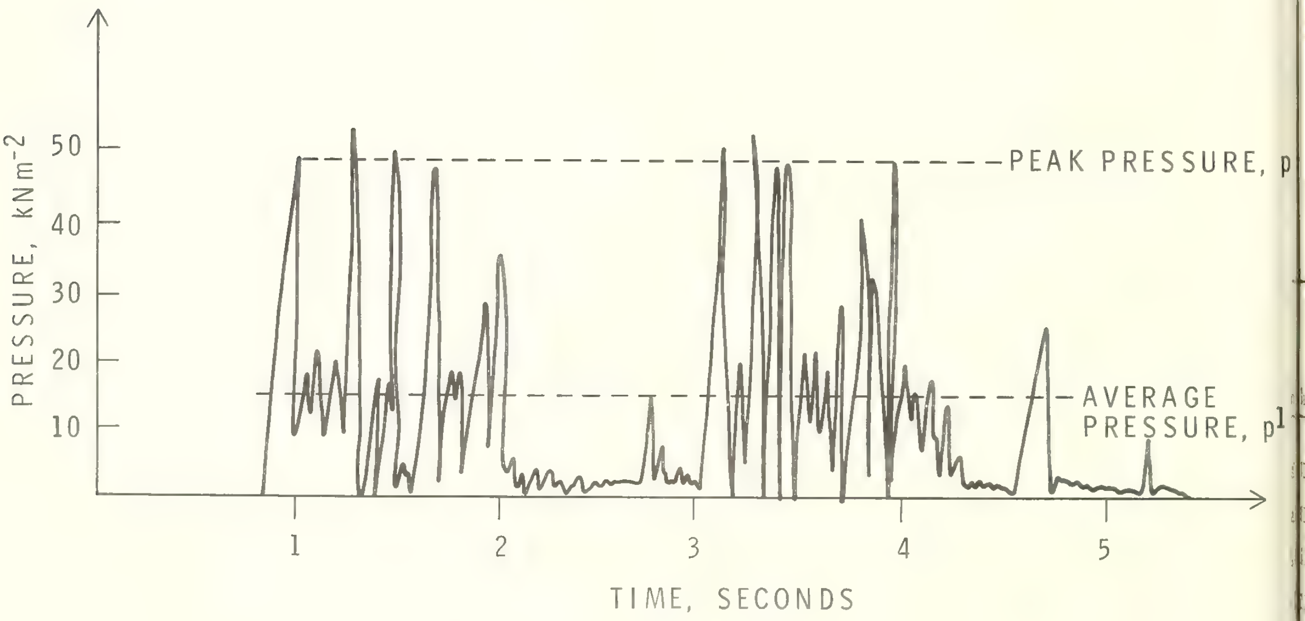

Figure 2.--Record of observed pressures.

Noteworthy is a series of pressure peaks with a duration of about 1 second and a recurrence period of about 2 seconds. They are probably the result of the complex nature of the start of the avalanches in irregular terrain. Snow would start to slide almost simultaneously at many places, but arrive at different times in the principal avalanche track, and, therefore, continue its motion in several mass waves. Recurring sets of peaks were not observed with minor avalanches that contained snow from only one small area of more or less uniform slope. Differences in particle size and bulk density are responsible for the fluctuations in pressure. Snowballs impinging on the load cells produced the peak pressures, and snowdust the low pressures.

A more uniform pressure with a small variation between extremes would probably be observed by using a cell with a larger measuring surface.

Analysis

The most advanced studies of avalanche dynamics are those by Salm (1967), Shen and Roper (1970), and Voellmy (1955). They considered the moving snow to be a compressible solid body or fluid.

If it is assumed that there is little compaction of the snow and little drag resistance associated with small obstacles, such as the load cells and the supporting frame used for the study, the impact pressure on unit surface area perpendicular to the flow can be expressed as:

$$p = \frac{v^2}{2} \rho$$

It was found that the observed peak pressures, p, agreed with the calculated pressures when v = the speed of the front of the avalanche, and ρ = the density of the deposited snow after the avalanche had stopped. (The density of the deposited snow would probably be equal to the density of large particles in the moving snow.)

The observed average pressure agreed with the calculated pressure

$$p = \frac{v^2}{2} \rho'$$

when ρ' was the average density of the following snow, or $\rho' = 0.3\ \rho$. Values of observed peak and average pressures, and corresponding calculated values are presented in table I.

TABLE I

OBSERVED AND CALCULATED IMPACT PRESSURES

te	Speed, v $m\ s^{-1}$	Density of Deposit, ρ $kg\ m^{-3}$	Peak Pressures p $kN\ m^{-2}$* Observed	Calculated	Average Pressure p' $kN\ m^{-2}$* Observed	Calculated	Depth of Flowing Snow m
ec 1970	35.7	350	182	222	62	67	2.5
ec 1970	53	310	256	435	105	131	1.8
an 1971	14.8	260	30	28	7.7	8.5	1.5
an 1971	14.7	225	35	24	8.3	7.2	0.9
an 1971	19.1	320	60	58	16	17.4	3.0
ec 1971	21.6	210	33	49	11.0	14.7	1.5
an 1972	16.9	300	38	43	11.7	12.9	1.5
an 1972	18.5	280	48	48	13.8	14.4	1.2

1N m^{-2} = 0.145 psi

Conclusions

The study indicates that for practical purposes the impact pressure produced by dry snow avalanches can be calculated from the speed of the avalanche front and the density of the deposited snow.

The observations were made on avalanches of relatively low speed with a small loading surface. In future studies it will be necessary to measure: (1) impact pressures on large surfaces; (2) impact pressures produced by avalanches with high speed; and (3) the distribution of the pressures over the full depth of avalanches.

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Oxford: 384.1:111.784. **Keywords:** Avalanches, snow management.

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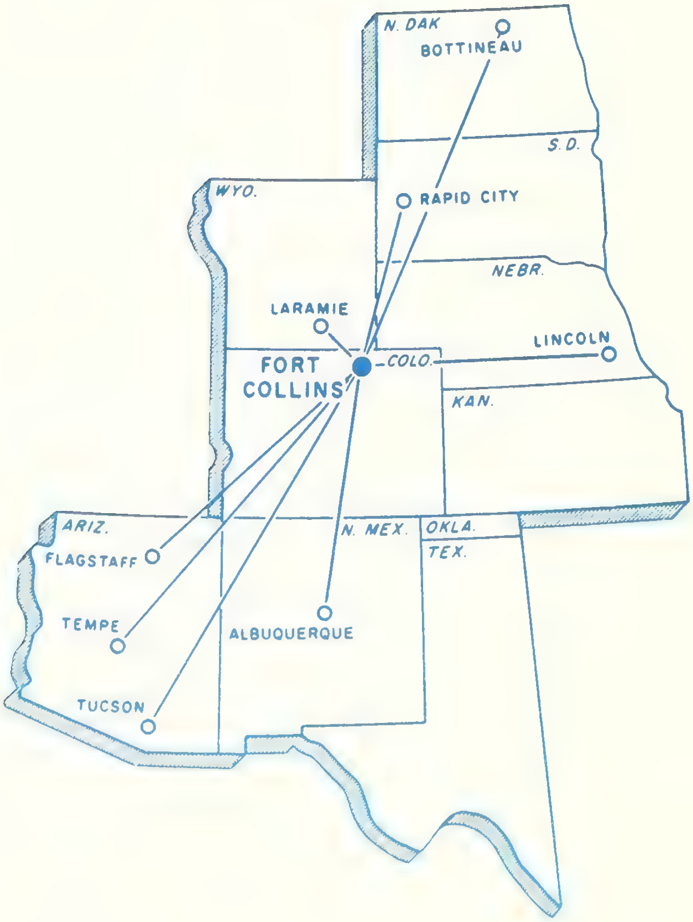
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THE SOUTHWESTERN PINYON-JUNIPER ECOSYSTEM: A Bibliography

By Earl F. Aldon and
H. W. Springfield

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Abstract

This bibliography is a compilation and classification of the pertinent literature for the pinyon-juniper ecosystem in the Southwest through 1972.

Oxford: 182.3:181.1. **Keywords:** Bibliography, ecosystems, *Pinus* spp., *Juniper* spp.

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THE SOUTHWESTERN PINYON-JUNIPER ECOSYSTEM:
A Bibliography

by

Earl F. Aldon, Principal Hydrologist

and

H. W. Springfield, Principal Range Scientist

Rocky Mountain Forest and Range Experiment Station[1]

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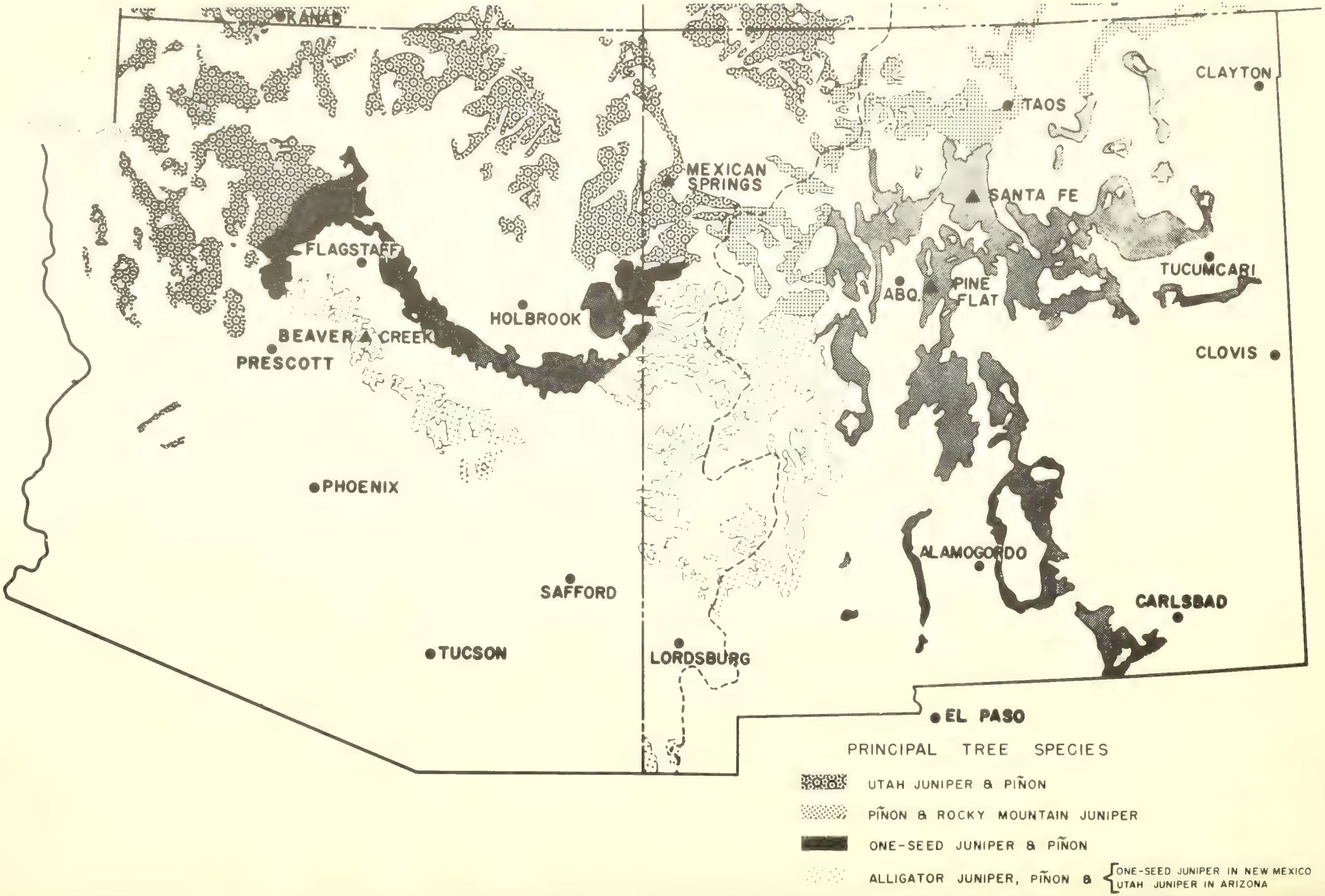
[1] *Central headquarters is maintained at Fort Collins, in cooperation with Colorado State University; authors are assigned to the Station's Research Work Unit at Albuquerque, in cooperation with University of New Mexico.*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PHOENIX
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SAFFORD
CARLSBAD
TUCSON
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EL PASO
PRINCIPAL TREE SPECIES
UTAH JUNIPER & PIÑON
PIÑON & ROCKY MOUNTAIN JUNIPER
ONE-SEED JUNIPER & PIÑON
ALLIGATOR JUNIPER, PIÑON & {ONE-SEED JUNIPER IN NEW MEXICO / UTAH JUNIPER IN ARIZONA}

THE SOUTHWESTERN PINYON-JUNIPER ECOSYSTEM:
A Bibliography

Earl F. Aldon and H. W. Springfield

The pinyon-juniper ecosystem of the Southwest has received much attention but little understanding. Many want to convert part of it to grass for grazing. Others have tried to utilize and enhance products from these tree species (nuts, fuelwood, posts, and so forth). Before a balanced program of management of the type is possible, we need to be aware of what is known about this ecosystem, and what knowledge gaps need to be filled.

Pinyon-juniper covers about 33 million acres in Arizona and New Mexico. Physiographically, it lies just below, and usually forms a transition zone with, the ponderosa pine ecosystem. Its wide distribution, together with its multiple uses and products, make the pinyon-juniper ecosystem important. More and more, people are becoming aware of the pleasing esthetic qualities of living in and viewing this type.

The objective of this bibliography is to list—in a single place—all references pertaining to the pinyon-juniper ecosystem. It is limited. References to the type have been included only if the work was done in or pertains to the Southwest. Occasionally other references were included if we felt the information could be useful in the Southwest.

References are classified according to principal subject matter and are not cross indexed. For instance, references pertaining to the pinyon nut crop itself are listed under **Product Utilization**; those pertaining to managing trees to increase the nut crop are listed under **Silvics and Management Aspects**. For special references, it would be advisable to search several subject-matter categories.

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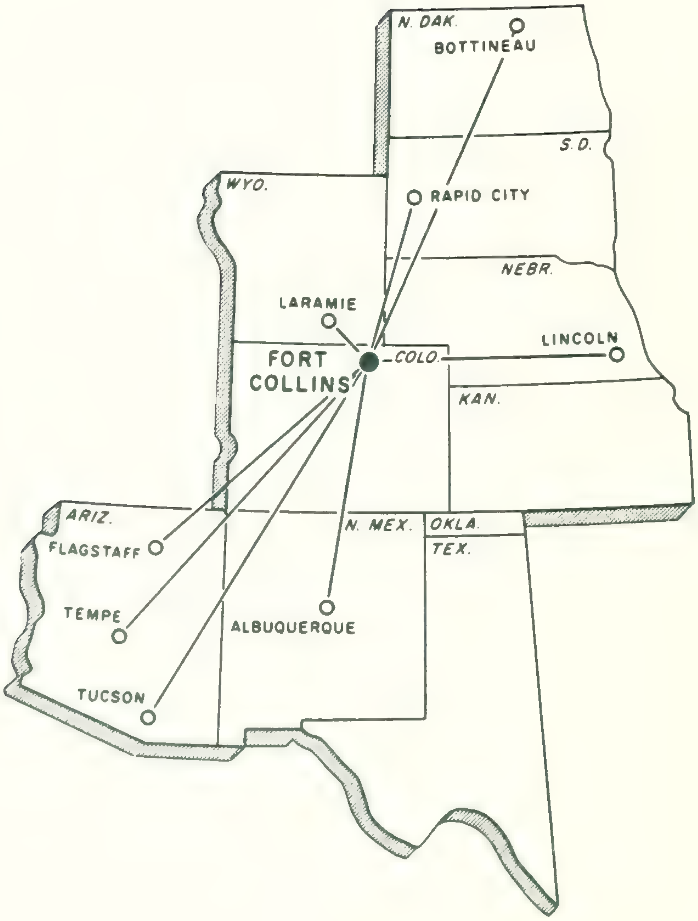
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AREAL SNOW COVER OBSERVATIONS IN THE CENTRAL ROCKIES, COLORADO.

By Arden D. Haeffner and
Charles F. Leaf

Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture

USDA Forest Service
General Technical Report RM-5
November 1973

Fort Collins, Colorado 80521

Abstract

Photographic records of areal snow cover depletion during the 1964-71 snowmelt seasons in the Fraser Experimental Forest, and in the Park Range from 1966-71, are summarized. Included are detailed estimates of snow cover extent on more than 90 hydrologic subunits which comprise the six watersheds photographed. Applications of these data in streamflow forecasting, water balance analyses, and snow cover duration are suggested.

Oxford: 587:116.12. **Keywords:** Aerial photography, photogrammetry, snow cover, streamflow forecasting.

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General Technical Report RM-5

November 1973

Areal Snow Cover Observations in the Central Rockies, Colorado

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Rocky Mountain Forest and Range Experiment Station[1]

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[1] *Central headquarters maintained at Fort Collins in cooperation with Colorado State University. Research reported here was conducted and partly financed in cooperation with the Division of Atmospheric Water Resources Management, Bureau of Reclamation, U.S. Department of the Interior.*

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Areal Snow Cover Observations in the Central Rockies, Colorado

Arden D. Haeffner and Charles F. Leaf

Introduction

Systematic observations of areal snow cover began more than 30 years ago in the United States. Most of the observations were used to develop techniques for streamflow forecasting, however, or for specialized hydrologic studies. As a result, these records have been short-term and not generally available for much of the West. Since 1945, however, the U.S. Corps of Engineers in the North Pacific Division has collected and published snow cover data in various subdrainages of the Columbia River Basin (Thoms 1961, 1969; Thoms and Wang 1969) to supplement and provide continuity to the index "snow course" information obtained by the U.S. Soil Conservation Service. The purpose of the summaries was to make snow cover information readily available for use in hydrologic studies by other agencies.

Snow cover information is becoming increasingly important in environmental studies, and in simulating and forecasting streamflow. Therefore, this Paper summarizes the basic areal snow cover observations collected from representative watersheds in Colorado, at the Fraser Experimental Forest near Fraser, and in the Park Range near Steamboat Springs. Our analyses and application of these data are also highlighted.

Aerial photographs were used to monitor the depletion (decrease in horizontal extent) of the snow cover. Three gaged subalpine watersheds were mapped at each area. Pictures were taken from 1964-71 in the Fraser Experimental Forest and 1966-71 in the Park Range.

Location and Description of Watersheds

The areas photographed are just west of the Continental Divide (fig. 1). The watersheds near Fraser are within the Fraser Experimental Forest about 45 miles due west of Denver. Those in the Park Range are tributaries of the Yampa River, about 9 miles northeast and 9 miles southeast of Steamboat Springs. Major topographic characteristics of each watershed are summarized in table 1, detailed maps and descriptions are in the appendix.

Fraser Experimental Forest

The three watersheds photographed in the Fraser Experimental Forest are tributaries of St. Louis Creek, a north-south oriented drainage. Lodgepole pine (Pinus contorta) and spruce-fir (Picea engelmannii-Abies lasiocarpa) forests occupy the majority of the watershed areas. Deep, gravelly soils overlay Precambrian bedrock; glaciation has influenced the topography. More detailed discussions of the geology, climate, and water yields are found in Garstka et al. (1958), Haeffner (1971), Leaf (1966, 1971), Leaf and Brink (1972a), and Retzer (1962).

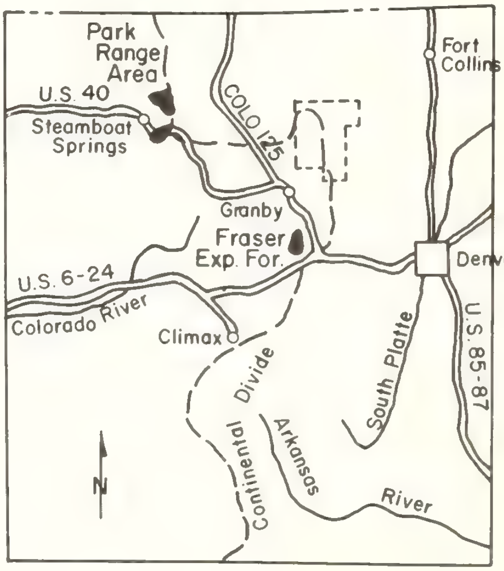

Figure 1.--Location map for the Fraser Experimental Forest and Park Range watersheds.

Table 1.--Major topographic characteristics of the study watersheds

Watershed	Area	Elevation		Approximate orientation	Area above timberline
		Range	Median		
	Acres	*Feet*	*Feet*		*Percent*
Fraser Experimental Forest:					
East St. Louis Creek	1,984	9,500-12,763	11,200	N-S	36
Deadhorse Creek	667	9,400-11,584	10,250	E-W	10
Lexen Creek	306	9,850-11,584	10,750	E-W	20
Park Range:					
South Fork Soda Creek	2,174	8,300-10,724	9,920	E-W	0
North Fork Fish Creek	1,435	9,800-10,724	10,260	NE-SW	0
West Fork Walton Creek	849	9,100- 9,728	9,280	NE-SW	0

Park Range

Three watersheds representative of the west slope of the Park Range were: South Fork Soda Creek, North Fork Fish Creek, and West Fork Walton Creek. The first two are paired watersheds northeast of Steamboat Springs, near Buffalo Pass. The headwaters of both of these watersheds consist of large alpine parks with interspersed narrow strips of spruce-fir trees generally oriented in a north-south direction. Below 10,300 feet, the forest grows in a more typical block pattern.[2] Aspen (Populus tremuloides), lodgepole pine, and extensive rock outcrops characterize the lower elevations of South Fork Soda Creek. Shallow, sparse soils overlay Precambrian bedrock; glaciation has influenced the topography.

West Fork Walton Creek is located southeast of Steamboat Springs on Rabbit Ears Pass. It supports stands of spruce-fir, lodgepole pine, and quaking aspen. Narrow strips of willows border the main stream channel and its tributaries. The soils on West Fork Walton Creek consist of deep weathered material with no indication of glacial activity. More detailed discussions of the vegetation, geology, and water yields are found in Dirmeyer,[3] Leaf and Brink (1972a), and Wilford.[2]

Observational Techniques

Aerial photography was used to get a permanent record of the areal extent of snow cover over the watersheds at about 10-day intervals during the snowmelt season. Oblique photographs were taken in 1964 at Fraser and in 1966 at the Park Range. Beginning in 1965 at Fraser and in 1967 at Park Range, vertical 9- by 9-inch photographs supplemented the obliques. Adverse flying conditions due to weather and mountainous topography affected the timing of the flights and quality of the photos. Most flights, however, provided sufficient photo overlap to achieve stereoscopic coverage at a photo scale of approximately 1:6,000.

Each watershed was subdivided into relatively homogeneous snow cover depletion units based on major physiographic and vegetation characteristics (Leaf 1969). The subdivisions and some physiographic characteristics are shown in the appendix (figs. 3-8). The snow cover in each of these units was estimated visually from the photographs with the aid of a stereoscope, weighted according to area, and summed to obtain the average watershed snow cover. Detailed estimates of the snow cover on each watershed and all subunits are presented in the appendix (tables 2-4). This information has provided input to a number of hydrologic studies of the Colorado subalpine forest ecosystem.

Analysis of Snow Cover Data

Brown and Dunford (1956) summarized the results of the first snow cover observations made at the Fraser Experimental Forest in 1950. This Paper reviews analyses of snow cover data collected in central Colorado since 1964.

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[2] *Wilford, B. H. 1967. Conditions and trends of forest stands within the Park Range Weather Modification study area, Routt National Forest. (Unpublished report submitted to and on file at Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.)*

[3] *Dirmeyer, R. D. 1967. Geological features affecting hydrological characteristics of Park Range experimental area. (Unpublished report submitted to and on file at Rocky Mt. For. and Range Exp. Stn. Fort Collins, Colo.)*

Snow Cover Depletion, Runoff Relationships

After collecting 4 years of snow cover data (1964-67) at Fraser, Leaf (1967) developed a mathematical model that expressed cumulative snow cover depletion (decrease in horizontal extent) and cumulative generated runoff[4] relationships as a function of time. He showed that "characteristic" cumulative functions for these watersheds could be developed because of the consistent nature of annual snow cover depletion and runoff. Additional data, that further defined these characteristic relationships, became the basis for forecasting residual streamflow in the central Colorado Rockies (Leaf 1969). Residual flows could be predicted from accumulated streamflow amounts at the time of the snow cover determinations.

Model for Updating Streamflow Forecasts

Annual differences in overwinter snowpack accumulation and the influence of precipitation during the snowmelt season were two factors contributing to scatter about the depletion-runoff functions, and therefore, forecasting errors. To account for these differences, a model for updating streamflow forecasts during the melt season was developed (Leaf and Haeffner 1971). It is based on the snow cover depletion versus runoff relationships and a precipitation index derived from April 30 storage gage measurements adjusted for subsequent precipitation during the snowmelt runoff season. Tests during 1 year showed that successive adjustments of the precipitation indices reduced initial forecast error from an average of 20 percent to approximately 10 percent when the flow remaining was still about 80 percent of the seasonal total.

Areal Snow Cover and Disposition of Snowmelt Runoff

In a water balance study, Leaf (1971) showed that integral snow cover measurements can be effectively utilized to identify watersheds and subunits within watersheds which contribute most efficiently to streamflow. The sequence of snow cover depletion and duration of the snowmelt season on the watersheds at Fraser reflected their water-yielding capability. Heterogeneous terrain produced a longer snowmelt season, which resulted in a less efficient conversion of snowmelt into streamflow. High efficiencies were apparently the result of (1) almost complete snow cover at the time when seasonal snowmelt rates were maximum on all aspects, (2) a delayed and short snow cover depletion season, and (3) relatively low recharge and evapotranspiration losses.

Snow Cover Duration

These studies of snow cover depletion have provided information on dates of final melt (last snow patches) on Bureau of Reclamation pilot project areas, where weather modification technology is being developed to increase water yields. Such data should be useful in analyzing the ecologic implications of weather modification. For example, ecologists have been concerned that an extended snowmelt season due to increased snow accumulation would have an adverse effect on wildlife and certain plant communities. Snow cover data obtained during wet and dry years over a wide range of meteorological conditions (1964-71 melt seasons) have given a good indication of the duration of snow cover on a long-term basis (Leaf and Brink 1972b).

Figure 2 shows duration of snow cover as a function of precipitation index (overwinter snow accumulation plus precipitation during the melt season) for three watersheds. It was found that the time required to reach a given percentage of snow cover is more dependent on precipitation index during low runoff years (index less than 100) than during high years. Thus, winter snow accumulation higher than normal apparently does not delay the disappearance of the last snow.

Photogrammetric Analysis of Snow Cover

A simple photogrammetric technique using a stereocomparator was developed to measure snow cover on selected key areas (Haeffner and Barnes 1972). By this method the percent snow cover was determined from the uncontrolled aerial photographs (photographs taken without benefit of ground control). The technique permitted: (1) a time savings in data reduction, (2) a reduced cost of aerial flights, (3) precise estimates of snow cover on an area, and (4) verification that the subjective estimates obtained using a folding stereoscope were relatively precise. In addition, the snow cover changes that were mapped on the smaller key area indexed the changes of snow cover not only on its complementary watershed, but also on nearby drainages.

[4] *Generated runoff is that quantity of snowmelt which results as streamflow (see U.S. Army 1956, Garstka et al. 1958).*

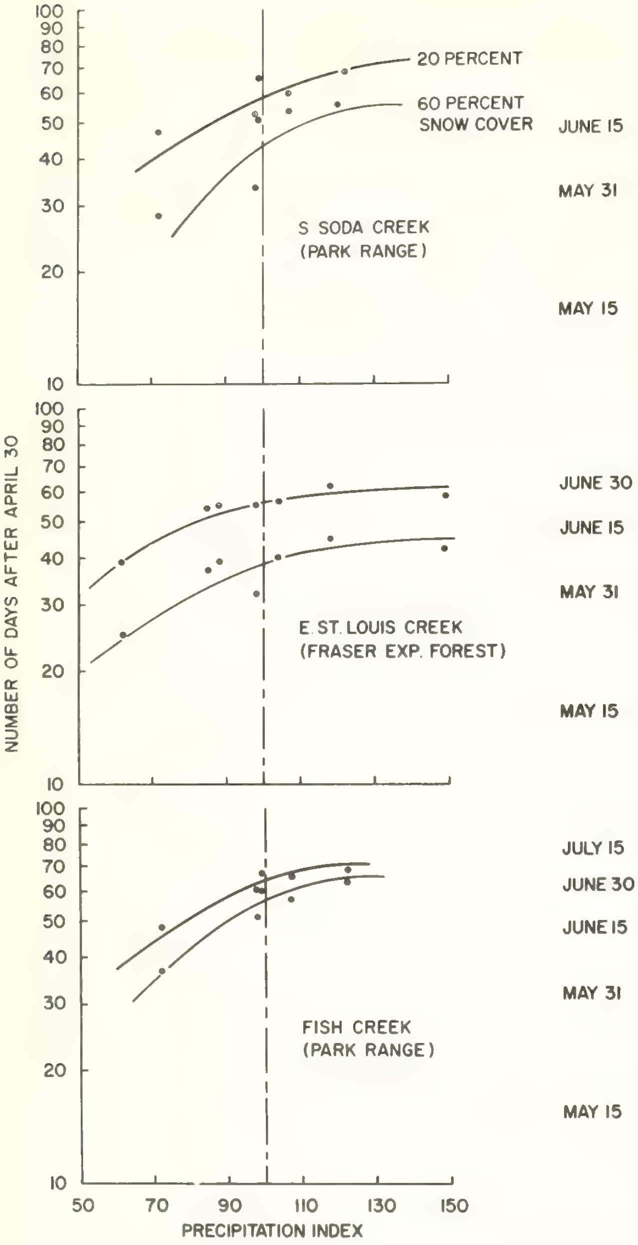

Figure 2.--Snow cover duration as a function of precipitation.

Discussion

The above summary has shown how we have used areal snow cover data for developing streamflow forecasting methods and for hydrologic analysis of subalpine watersheds.

Because these data may have other applications in ecosystems analyses, the basic snow cover estimates have been summarized (appendix, tables 2-4) in this report for use by others working in the Colorado subalpine forest zone.

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APPENDIX

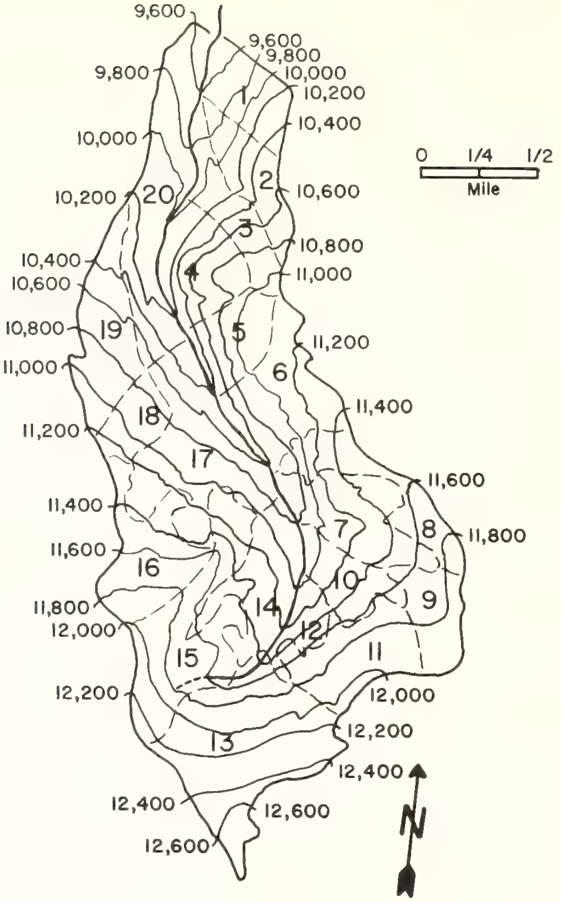

Figure 3.--East St. Louis Creek watershed (1,984 acres), Fraser Experimental Forest, by subunits with the following physiographic characteristics:

Subunit	Percent of total area	Median elevation (feet)	Aspect	Estimated percent of subunit forested	Forest type
1	4	9,900	WNW	100	Lodgepole pine
2	3	10,250	WNW	100	Lodgepole pine
3	3	10,250	NW	100	Lodgepole pine, spruce-fir
4	5	10,450	WNW	100	Spruce-fir
5	4	10,850	WSW	100	Spruce-fir
6	6	11,050	SW	95	Spruce-fir
7	5	11,250	W	95	Spruce-fir
8	4	11,450	W	5	Spruce-fir
9	4	11,800	NW	5	Spruce-fir
10	3	11,300	WNW	100	Spruce-fir
11	4	11,850	NW	0	--
12	2	11,250	NW	100	Spruce-fir
13	11	12,200	NNW	0	--
14	5	11,200	ENE	95	Spruce-fir
15	8	11,700	ENE	0	--
16	5	11,650	N	0	--
17	9	10,800	NNE	100	Spruce-fir
18	2	10,950	NE	100	Spruce-fir
19	5	10,700	NE	100	Lodgepole pine, spruce-fir
20	9	10,050	ENE	100	Lodgepole pine, spruce-fir

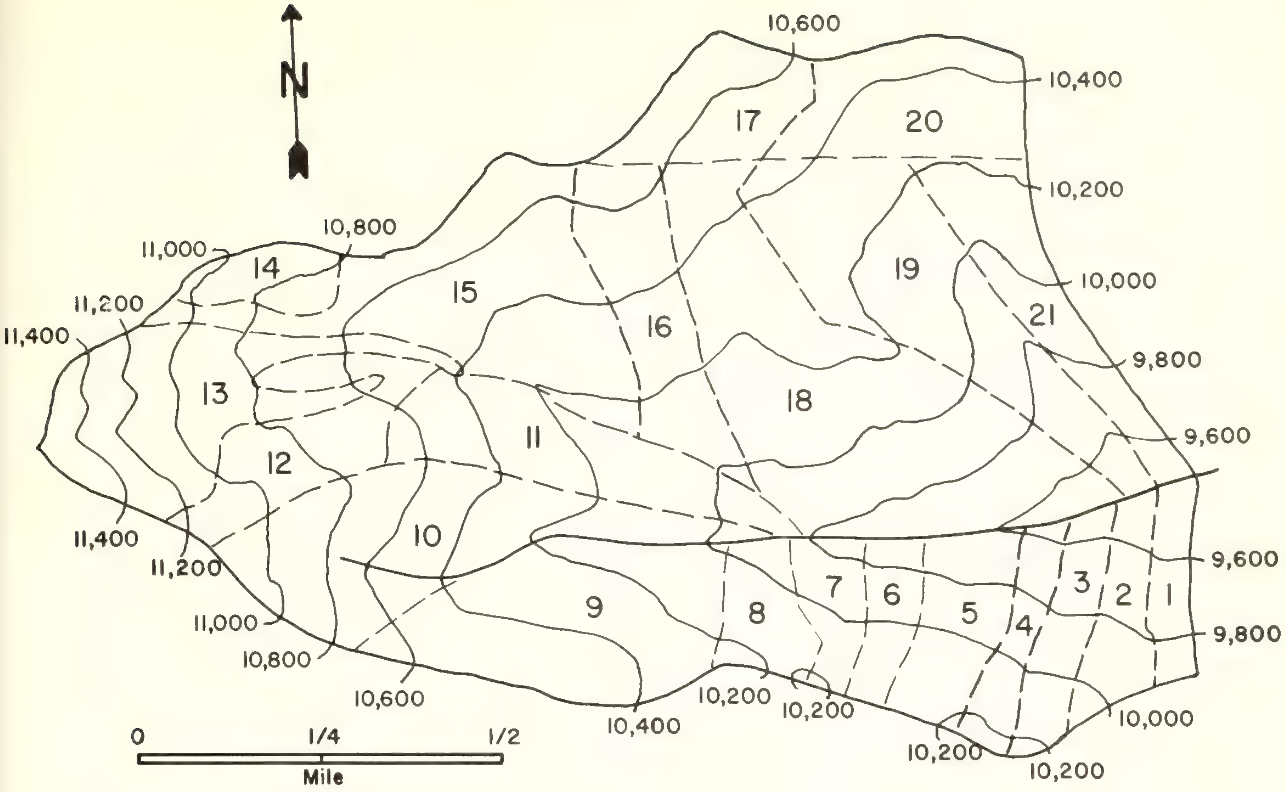

Figure 4.--Deadhorse Creek watershed (667 acres), Fraser Experimental Forest, by subunits with the following physiographic characteristics:

Subunit	Percent of total area	Median elevation (feet)	Aspect	Estimated percent of subunit forested	Forest type
1	1	9,650	N	100	Lodgepole pine, spruce-fir
2	2	9,700	NNE	100	Lodgepole pine
3	3	9,850	N	100	Lodgepole pine
4	2	9,900	NNE	100	Lodgepole pine
5	2	10,000	NNE	100	Lodgepole pine, spruce-fir
6	2	9,950	N	100	Lodgepole pine, spruce-fir
7	1	10,000	NNE	100	Spruce-fir
8	2	10,100	ENE	100	Spruce-fir
9	8	10,250	NNE	100	Lodgepole pine, spruce-fir
10	9	10,400	E	100	Lodgepole pine
11	5	10,200	ENE	100	Lodgepole pine, spruce-fir
12	4	10,800	NE	100	Spruce-fir
13	8	11,150	E	0	--
14	2	10,850	SSE	10	Spruce-fir
15	12	10,550	SSE	100	Lodgepole pine
16	6	10,350	SSE	100	Lodgepole pine
17	3	10,600	SE	[1]100	Lodgepole pine
18	12	10,250	SE	100	Lodgepole pine
19	8	10,050	ESE	100	Lodgepole pine
20	5	10,350	S	[1]100	Lodgepole pine
21	5	9,950	SSW	100	Lodgepole pine

[1] Cutover area.

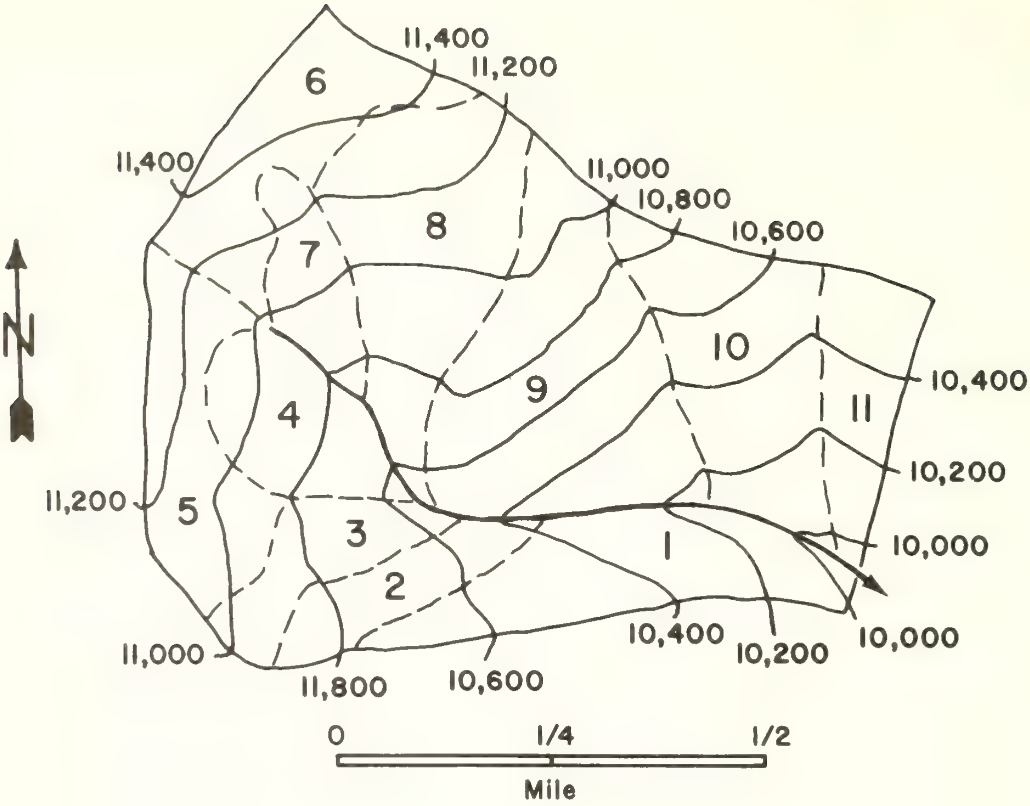

Figure 5.--Lexen Creek watershed (306 acres), Fraser Experimental Forest, by subunits with the following physiographic characteristics:

Subunit	Percent of total area	Median elevation (feet)	Aspect	Estimated percent of subunit forested	Forest type
1	9	10,400	NE	100	Lodgepole pine, spruce-fir
2	3	10,700	ENE	100	Spruce-fir
3	8	10,800	ENE	100	Spruce-fir
4	8	10,900	ESE	100	Spruce-fir
5	8	11,150	E	0	--
6	12	11,400	SSE	0	--
7	4	11,000	SSE	100	Spruce-fir
8	8	11,050	S	100	Lodgepole pine, spruce-fir
9	22	10,600	SE	100	Lodgepole pine
10	11	10,400	SSE	100	Lodgepole pine
11	7	10,300	SSW	100	Lodgepole pine

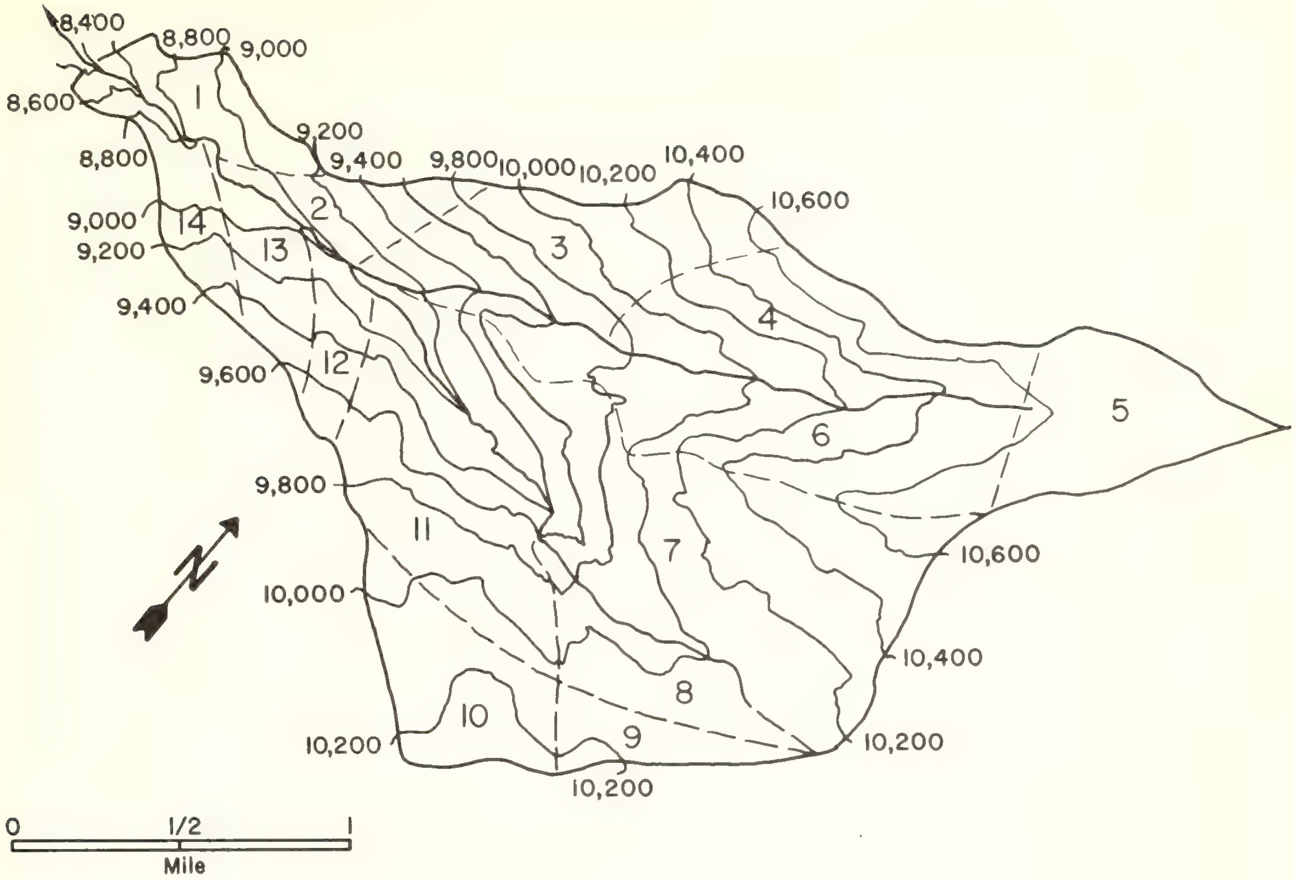

Figure 6.--South Fork Soda Creek watershed (2,174 acres), Park Range, by subunits with the following physiographic characteristics:

Subunit	Percent of total area	Median elevation (feet)	Aspect	Estimated percent of subunit forested	Forest type
1	4	8,900	SSW	70	Aspen
2	5	9,300	S	30	Aspen, lodgepole pine, spruce-fir
3	8	9,900	S	30	Lodgepole pine, spruce-fir
4	9	10,400	S	5	Spruce-fir
5	6	10,650	SW	[1]20	Spruce-fir
6	11	10,200	WNW	90	Spruce-fir
7	24	10,100	SSW	30	Lodgepole pine, spruce-fir
8	4	10,000	NW	30	Lodgepole pine, spruce-fir
9	3	10,150	NNW	40	Lodgepole pine, spruce-fir
10	6	10,150	NNW	40	Spruce-fir
11	9	9,700	N	30	Spruce-fir
12	4	9,400	N	10	Spruce-fir
13	4	9,200	NNW	10	Lodgepole pine
14	3	8,900	NW	10	Lodgepole pine

[1] Trees growing in strips.

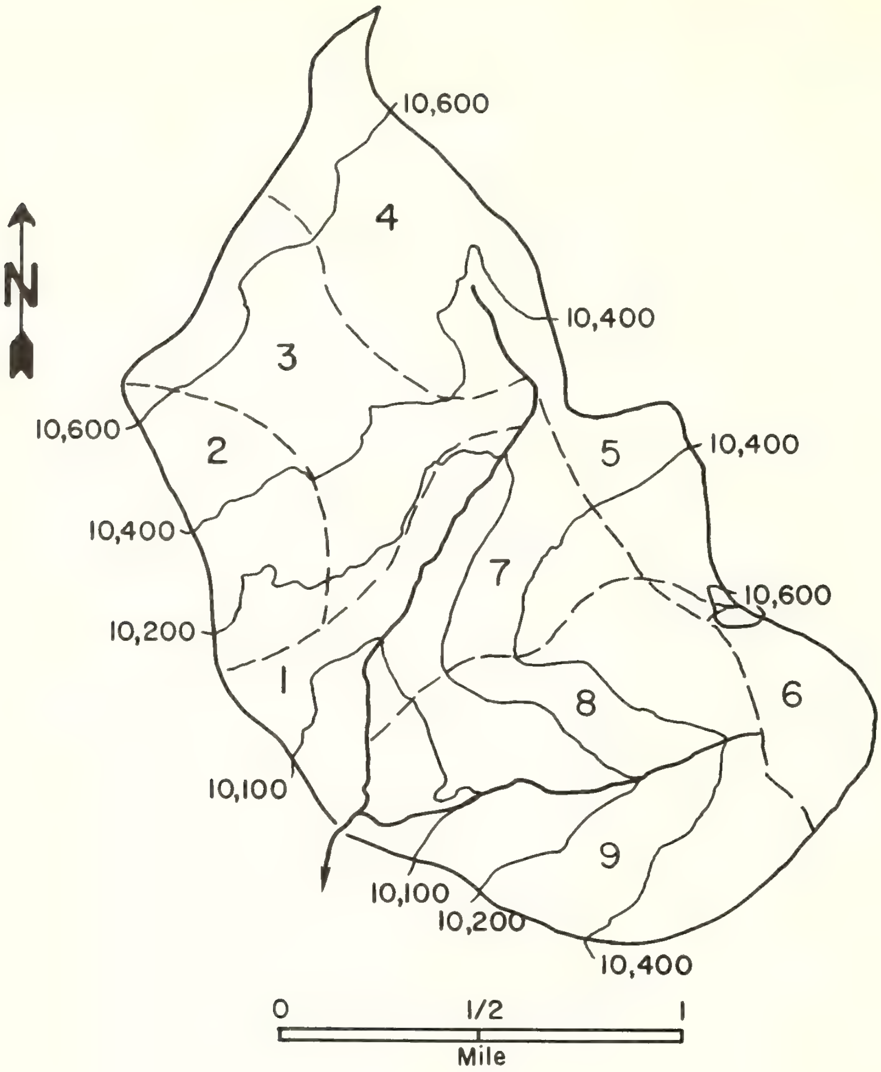

Figure 7.--North Fork Fish Creek watershed (1,435 acres), Park Range, by subunits with the following physiographic characteristics:

Subunit	Percent of total area	Median elevation (feet)	Aspect	Estimated percent of subunit forested	Forest type
1	14	10,000	SE	40	Spruce-fir
2	11	10,400	SE	20	Spruce-fir
3	11	10,500	SE	20	Spruce-fir
4	13	10,500	ESE	50	Spruce-fir
5	7	10,400	NNW	[1]20	Spruce-fir
6	6	10,500	W	[1]20	Spruce-fir
7	9	10,250	WNW	[1]40	Spruce-fir
8	14	10,400	SSW	[1]30	Spruce-fir
9	14	10,300	NW	60	Spruce-fir

[1] Trees growing in strips.

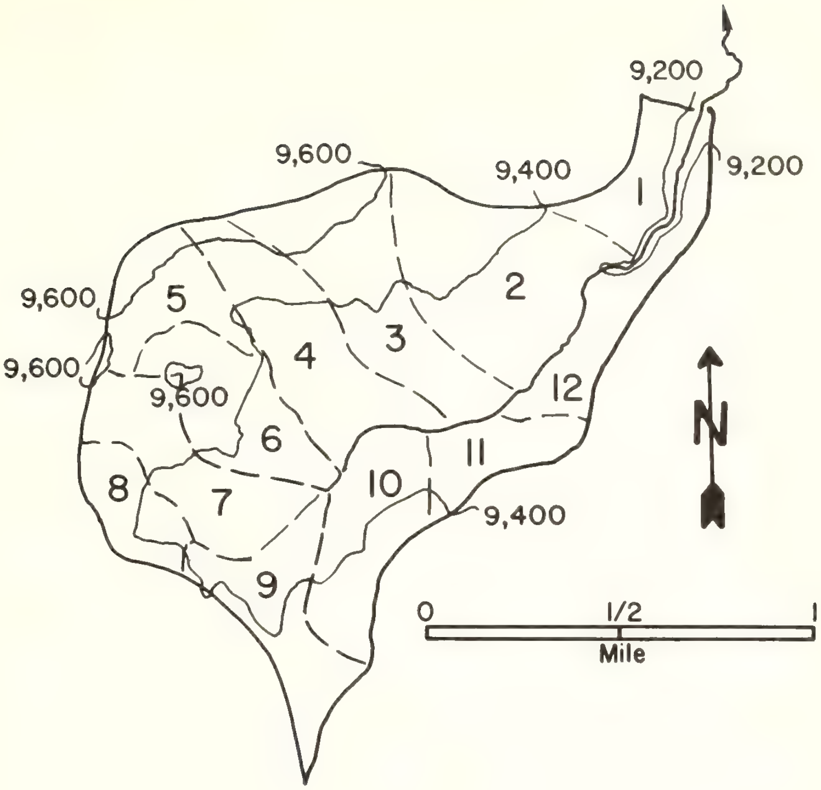

Figure 8.--West Fork Walton Creek watershed (849 acres), Park Range, by subunits with the following physiographic characteristics:

Subunit	Percent of total area	Median elevation (feet)	Aspect	Estimated percent of subunit forested	Forest type
1	4	9,250	ESE	95	Lodgepole pine
2	12	9,350	SE	40	Lodgepole pine
3	10	9,400	SSE	40	Lodgepole pine
4	8	9,350	S	5	Aspen
5	9	9,600	SE	0	--
6	9	9,400	SE	60	Lodgepole pine, spruce-fir
7	9	9,400	SSE	5	Lodgepole pine, spruce-fir
8	8	9,450	ESE	70	Spruce-fir
9	9	9,450	NW	90	Lodgepole pine, spruce-fir
10	9	9,400	NW	80	Lodgepole pine
11	4	9,350	NNW	60	Lodgepole pine
12	8	9,300	NW	100	Lodgepole pine

Table 2.--Estimated areal snow cover (percent, snow-covered area) by flight date, for total watershed and subunits of each watershed, Fraser Experimental Forest, 1964-71

Flight date	Total watershed	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
EAST ST. LOUIS CREEK																						
1964--																						
May 7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
May 14	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
May 22	89	50	50	100	85	85	85	100	85	85	100	85	100	85	100	85	90	100	100	100	95	
June 6	54	0	0	35	20	45	50	85	50	65	100	70	100	70	100	70	70	75	75	10	0	
June 13	37	0	0	20	10	15	20	75	30	35	85	35	100	40	100	50	50	60	50	0	0	
June 25	14	0	0	0	0	0	0	20	5	15	35	20	60	25	30	30	25	20	10	0	0	
1965--																						
May 16	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
May 28	97	85	100	100	100	85	90	100	95	99	100	99	100	100	100	100	100	100	100	100	92	
June 19	50	0	0	35	25	50	35	90	40	60	100	50	100	60	100	70	80	70	45	5	0	
June 26	32	0	0	20	5	15	5	45	25	40	80	35	85	45	70	45	70	50	20	0	0	
July 4	14	0	0	2	0	0	2	15	5	15	25	20	45	20	40	30	25	20	10	0	0	
1966--																						
April 30	99	90	100	100	100	90	95	100	95	99	100	99	100	100	100	100	100	100	100	100	100	
May 18	83	40	70	90	90	80	80	100	90	90	100	90	100	90	100	90	85	95	100	75	45	
May 23	63	0	0	55	60	55	50	90	70	75	100	70	100	75	100	85	85	80	70	45	5	
May 30	48	0	0	40	30	40	35	75	50	60	95	60	90	60	90	60	75	70	35	0	0	
June 6	26	0	0	3	0	5	2	40	15	30	80	40	55	40	50	50	50	35	15	0	0	
June 24	6	0	0	0	0	0	0	0	0	0	25	10	40	15	0	15	15	0	0	0	0	
1967--																						
April 28	100	98	100	100	100	98	100	100	97	98	100	99	100	100	100	100	100	100	100	100	100	
May 16	93	85	100	100	100	75	90	100	90	90	100	90	100	90	100	90	90	100	100	100	90	
June 2	75	30	50	75	75	75	65	95	80	80	100	80	100	85	100	85	85	90	80	60	25	
June 17	40	0	0	20	0	30	15	50	40	50	95	50	90	60	80	60	80	55	35	0	0	
June 23	26	0	0	3	0	5	2	40	15	30	80	40	55	40	50	50	50	35	15	0	0	
July 2	6	0	0	0	0	0	0	0	0	0	10	10	30	15	0	30	20	0	0	0	0	
1968--																						
May 28	99	100	100	100	99	99	100	100	95	97	100	98	100	99	100	100	100	100	100	100	100	
June 3	75	30	50	75	75	75	65	95	80	80	100	80	100	85	100	85	85	90	80	60	25	
June 9	54	0	0	40	30	60	50	85	50	60	100	60	100	65	100	75	85	75	55	5	2	
June 19	42	0	0	30	5	20	25	55	35	55	95	50	90	60	85	65	80	55	20	2	0	
June 29	10	0	0	0	0	0	0	5	0	5	10	15	40	25	10	30	20	10	0	0	0	
July 5	6	0	0	0	0	0	0	0	0	0	0	10	15	20	0	25	20	0	0	0	0	
1969--																						
May 1	100	100	100	100	100	98	100	100	97	98	100	99	100	98	100	100	100	100	100	100	100	
May 15	94	75	95	100	100	80	90	100	90	98	100	98	100	98	100	98	98	100	100	100	75	
May 25	75	20	40	65	75	75	70	95	80	80	100	80	100	85	100	85	90	95	80	60	25	
June 4	50	0	0	40	30	40	40	75	40	60	90	60	95	70	90	75	80	70	35	0	0	
July 2	11	0	0	0	0	0	2	15	5	15	20	15	40	20	25	20	25	15	0	0	0	
1970--																						
June 2	75	30	50	75	75	65	65	95	80	80	100	80	100	85	100	85	85	90	90	70	25	
June 19	41	0	0	30	5	20	25	55	35	55	95	50	90	60	80	65	80	55	25	2	0	
July 1	11	0	0	0	0	0	2	15	5	15	20	15	40	20	25	20	25	15	0	0	0	
1971--																						
June 7	89	70	85	100	90	85	90	100	60	90	100	75	100	85	100	95	95	100	100	100	70	
June 12	79	55	75	90	80	60	80	95	50	80	100	65	100	75	100	90	85	95	100	90	50	
June 23	37	0	0	30	10	10	20	30	25	50	90	40	90	50	80	65	60	60	55	5	0	
DEADHORSE CREEK																						
1964--																						
May 7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
May 14	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	95	80	100	75
May 22	73	100	100	100	100	100	100	100	100	100	100	100	100	100	80	75	50	80	20	30	75	15
June 6	18	0	0	0	0	0	0	0	10	40	20	15	90	80	25	15	0	0	0	0	0	0
June 13	10	0	0	0	0	0	0	0	0	15	5	5	60	65	5	5	0	0	0	0	0	0
June 25	5	0	0	0	0	0	0	0	0	0	0	0	25	45	0	0	0	0	0	0	0	0
1965--																						
May 15	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99
May 28	87	100	100	100	100	100	100	100	100	100	100	100	100	99	98	98	95	95	60	75	75	15
June 19	18	0	0	0	0	0	0	0	20	45	20	30	80	70	5	15	2	2	0	0	0	0
June 26	10	0	0	0	0	0	0	0	0	10	2	20	75	60	2	5	0	0	0	0	0	0
July 4	4	0	0	0	0	0	0	0	0	0	0	2	15	40	0	0	0	0	0	0	0	0
1966--																						
April 30	87	100	100	100	100	100	100	100	100	100	100	100	100	99	85	98	90	90	60	75	65	25
May 18	55	40	50	70	70	70	70	70	80	90	80	100	100	90	10	65	40	10	15	35	0	0
May 23	26	5	15	25	30	40	30	30	50	70	25	60	85	70	5	15	3	0	0	1	0	0
May 30	13	0	0	0	0	0	0	0	0	25	5	30	75	65	2	2	0	0	0	0	0	0
June 6	5	0	0	0	0	0	0	0	0	5	0	2	50	30	0	0	0	0	0	0	0	0
June 24	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Flight date	Total water-shed	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
DEADHORSE CREEK--CONTINUED																						
1967--																						
April 28	93	100	100	100	100	100	100	100	100	100	100	100	100	99	99	97	95	90	75	95	85	60
May 16	84	100	100	100	100	100	100	100	100	100	100	100	100	95	85	90	90	80	55	75	70	20
June 17	12	0	0	0	0	0	0	0	0	25	5	30	75	65	0	2	0	0	0	0	0	0
June 23	8	0	0	0	0	0	0	0	0	15	0	5	50	55	0	0	0	0	0	0	0	0
July 2	1	0	0	0	0	0	0	0	0	0	0	0	2	15	0	0	0	0	0	0	0	0
1968--																						
May 28	92	100	100	100	100	100	100	100	100	100	100	100	100	99	99	100	100	98	65	90	85	40
June 3	48	35	50	50	60	70	65	70	75	90	75	100	100	80	15	55	25	5	5	20	0	0
June 9	18	0	5	10	15	15	15	20	25	45	15	45	80	70	2	2	0	0	0	0	0	0
June 19	14	0	0	0	0	0	5	10	10	35	10	30	75	65	0	2	0	0	0	0	0	0
June 29	3	0	0	0	0	0	0	0	0	0	0	0	5	35	0	0	0	0	0	0	0	0
July 5	1	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0
1969--																						
May 1	93	100	100	100	100	100	100	100	100	100	100	100	100	99	99	97	95	90	75	95	85	60
May 15	82	100	100	100	100	100	100	100	100	100	100	100	100	95	80	90	85	65	50	80	60	15
May 25	54	40	50	70	70	70	70	70	80	95	90	100	100	90	10	75	35	10	10	20	0	0
June 4	19	0	5	10	15	15	15	20	25	50	20	50	85	70	2	2	0	0	0	0	0	0
1970--																						
June 2	57	40	50	70	70	70	70	70	80	90	85	100	100	90	20	65	50	10	15	35	2	0
July 1	5	0	0	0	0	0	0	0	0	0	0	0	2	20	0	0	0	0	0	0	0	0
1971--																						
June 7	85	100	100	100	100	100	100	100	100	100	100	100	100	95	80	100	90	80	60	75	50	20
June 12	69	90	90	95	95	95	100	100	100	100	80	100	100	80	40	85	70	40	30	60	5	10
June 23	21	0	0	0	0	0	0	10	20	70	30	60	70	60	5	10	0	0	0	0	0	0
LEXEN CREEK																						
1964--																						
May 7	100	100	100	100	100	100	100	100	100	100	100	100										
May 14	100	100	100	100	100	100	100	100	100	100	100	100										
May 22	98	100	100	100	100	100	100	100	100	100	100	75										
June 6	46	30	75	100	95	98	95	50	50	0	0	0										
June 13	25	10	25	50	40	70	70	25	15	0	0	0										
June 25	15	0	0	0	5	60	55	10	0	0	0	0										
1965--																						
May 16	100	100	100	100	100	100	100	100	100	100	100	100										
May 28	100	100	100	100	100	100	100	100	100	100	100	100										
June 19	46	45	75	95	85	85	95	50	50	5	0	0										
June 26	22	20	30	50	40	65	65	20	15	0	0	0										
July 4	9	0	0	0	2	45	45	3	0	0	0	0										
1966--																						
April 30	100	100	100	100	100	100	100	100	100	100	100	100										
May 18	79	100	100	100	100	97	95	80	85	60	50	40										
May 23	55	75	95	97	90	90	90	55	60	15	5	2										
May 30	30	30	50	55	50	70	70	15	15	5	0	0										
June 6	11	2	20	10	1	45	45	2	0	0	0	0										
June 24	6	0	0	0	0	30	30	0	0	0	0	0										
1967--																						
April 28	100	100	100	100	100	100	100	100	100	100	100	100										
May 16	91	100	100	100	100	100	99	90	100	80	80	75										
June 17	30	30	40	55	65	70	70	15	15	5	0	0										
June 23	12	2	25	15	1	45	45	2	2	0	0	0										
July 2	8	0	0	0	0	40	40	0	0	0	0	0										
1968--																						
May 28	98	100	100	100	100	100	100	100	100	100	100	98										
June 3	75	95	100	100	100	95	95	85	85	50	40	30										
June 9	51	60	80	95	90	90	90	60	60	15	0	0										
June 19	29	25	45	55	45	75	75	20	25	0	0	0										
June 29	9	0	0	10	[illegible]	40	40	0	0	0	0	0										
1969--																						
May 1	100	100	100	100	100	100	100	100	100	100	100	95										
May 15	93	100	100	100	100	100	95	99	100	85	85	80										
May 25	76	100	100	100	100	95	95	75	80	55	45	35										
June 4	40	50	60	75	80	80	80	30	30	5	0	0										
1970--																						
June 2	75	95	100	100	100	95	95	85	85	50	40	30										
June 19	29	25	30	55	45	75	75	20	25	0	0	0										
June 24	22	20	20	50	40	65	65	20	15	0	0	0										
July 1	9	0	0	0	2	45	45	3	0	0	0	0										
1971--																						
June 7	84	100	100	100	100	90	90	90	100	80	50	50										
June 12	76	95	95	100	100	90	90	80	90	60	40	30										
June 23	36	50	60	80	50	70	70	20	30	10	0	0										

Table 3.--Estimated areal snow cover (percent, snow-covered area) by flight date, for total watershed and subunits of each watershed, Park Range, 1967-71

Flight date	Total watershed	1	2	3	4	5	6	7	8	9	10	11	12	13	14
						SOUTH FORK SODA CREEK									
1967--															
April 28	96	15	99	100	100	100	100	100	100	100	100	100	100	100	99
May 16	94	10	75	99	100	100	100	99	100	100	100	100	100	99	90
June 2	80	0	10	75	90	100	99	80	99	100	100	98	80	80	65
June 17	65	0	0	40	80	99	90	60	97	100	97	87	75	25	0
June 23	46	0	0	20	40	95	80	45	95	98	97	70	30	7	0
July 2	22	0	0	15	10	55	50	15	50	30	45	25	1	0	0
1968--															
May 28	97	25	98	100	100	100	100	100	100	100	100	100	100	100	95
June 3	85	2	35	85	97	100	99	85	100	100	100	99	85	85	70
June 9	80	2	5	65	90	100	100	97	100	100	100	99	85	75	50
June 19	69	0	0	50	80	99	95	85	100	100	100	90	85	50	0
July 5	18	0	0	5	5	60	50	15	45	25	35	15	0	0	0
July 13	4	0	0	0	1	35	15	0	2	2	2	1	0	0	0
1969--															
May 10	92	10	60	95	98	100	100	95	100	100	100	100	99	98	95
May 15	86	15	15	75	95	100	100	95	100	100	100	99	90	90	80
May 25	74	1	2	55	85	100	97	90	100	100	100	90	85	65	25
June 4	58	0	0	25	50	97	85	80	95	100	98	80	55	15	0
July 2	6	0	0	0	1	40	25	0	1	1	1	1	0	0	0
1970--															
June 2	90	30	50	85	99	100	99	100	100	100	100	99	90	85	80
June 21	66	0	0	40	80	99	90	85	97	100	97	90	75	35	0
July 1	39	0	0	15	30	65	70	50	80	85	80	40	5	5	0
July 15	1	0	0	1	1	10	2	1	2	3	0	0	0	0	0
1971--															
June 12	85	10	20	80	95	100	100	99	100	100	100	95	90	80	70
June 23	57	0	0	20	50	95	80	75	98	100	98	80	50	15	0
July 8	16	0	0	2	5	55	55	10	35	15	20	10	0	0	0
July 11	7	0	0	0	2	40	35	0	5	2	5	1	0	0	0
						NORTH FORK FISH CREEK									
1967--															
April 28	100	100	100	100	100	100	100	100	100	100					
May 16	100	100	100	100	100	100	100	100	100	100					
June 2	100	100	99	100	100	100	100	100	100	100					
June 17	99	99	97	99	100	100	100	99	99	99					
June 23	92	80	90	92	98	99	95	95	92	92					
July 2	50	5	20	65	70	85	77	67	20	75					
1968--															
May 28	100	100	100	100	100	100	100	100	100	100					
June 3	100	100	100	100	100	100	100	100	100	100					
June 9	100	99	100	100	100	100	100	100	100	100					
June 19	99	98	100	100	99	100	99	100	99	100					
July 5	40	7	15	45	55	80	80	60	10	55					
July 13	6	0	1	2	20	15	10	2	1	7					
1969--															
May 10	100	100	100	100	100	100	100	100	100	100					
May 15	100	100	100	100	100	100	100	100	100	100					
May 25	100	100	100	100	100	100	100	100	100	100					
June 4	96	92	85	95	100	100	99	100	95	98					
July 2	14	0	0	15	20	45	40	3	2	30					
1970--															
June 2	100	100	100	100	100	100	100	100	100	100					
June 21	99	98	99	100	99	100	98	100	99	100					
July 1	68	50	50	75	80	90	80	85	40	85					
July 15	2	0	0	0	5	5	3	1	0	5					
1971--															
June 12	100	100	100	99	100	100	100	100	100	100					
June 23	93	90	80	90	100	95	95	100	95	95					
July 8	34	5	15	45	45	70	70	35	10	50					
July 11	17	2	10	20	25	40	40	10	5	25					
						WEST FORK WALTON CREEK									
1967--															
April 28	100	100	100	100	100	100	100	100	100	100	100	100	100		
May 16	100	100	100	100	100	100	100	100	100	100	100	100	100		
June 2	78	25	85	75	70	50	80	65	80	100	100	100	90		
June 17	8	3	2	0	3	0	7	0	7	25	20	20	20		
June 23	3	0	0	0	0	0	5	0	5	7	7	5	5		
July 2	0	0	0	0	0	0	0	0	0	0	0	0	0		
1968--															
May 28	100	100	100	100	100	100	100	100	100	100	100	100	100		
June 3	100	99	100	100	99	100	97	100	100	100	100	100	100		
June 9	81	40	80	75	75	50	75	80	95	100	100	100	99		
June 19	35	15	10	10	5	15	40	25	20	80	75	75	75		
June 29	4	1	0	0	0	0	5	2	2	15	15	10	5		
July 5	0	0	0	0	0	0	0	0	0	1	1	1	0		
1969--															
May 10	100	100	100	100	100	99	99	100	100	100	100	100	100		
May 15	91	80	97	95	85	70	85	90	90	100	100	100	100		
May 25	40	20	15	15	10	25	40	25	20	80	85	90	85		
June 4	6	0	0	0	0	0	5	0	5	20	25	15	10		
July 2	0	0	0	0	0	0	0	0	0	0	0	0	0		
1970--															
June 2	100	100	100	100	100	99	99	99	100	100	100	100	100		
June 21	32	10	5	5	3	3	35	25	30	75	70	70	70		
July 1	5	0	0	0	0	0	1	2	0	15	15	15	15		
July 15	0	0	0	0	0	0	0	0	0	0	0	0	0		
1971--															
June 12	88	80	95	90	70	70	80	85	85	100	100	100	100		
June 23	27	5	2	2	2	2	30	20	40	55	65	60	65		
July 8	5	0	0	0	0	0	2	0	0	15	15	15	15		
July 11	0	0	0	0	0	0	0	0	0	0	0	0	0		

Table 4.--Summary of areal snow cover (percent, snow-covered area) by flight date, for three watersheds on Fraser Experimental Forest, 1964-71, and three watersheds in the Park Range, 1966-71

FRASER EXPERIMENTAL FOREST				PARK RANGE			
Flight date	East St. Louis	Dead-horse	Lexen	Flight date	South Fork Soda Creek	North Fork Fish Creek	West Fork Walton Creek
1964--May 7	100	100	100				
May 14	100	97	100				
May 22	89	73	98				
June 6	54	18	46				
June 13	37	10	25				
June 25	14	5	15				
1965--May 16	100	100	100				
May 28	97	87	100				
June 19	50	18	46				
June 26	32	10	22				
July 4	14	4	9				
1966--April 30	99	87	100	1966--April 30	100	100	100
May 18	83	55	79	May 18	80	100	75
May 23	63	26	55	May 23	70	100	35
May 30	48	13	30	May 29	55	95	5
June 6	26	5	11	June 6	40	60	0
June 24	6	1	6	June 23	5	5	0
1967--April 28	100	93	100	1967--April 28	96	100	100
May 16	93	84	91	May 16	94	100	100
June 2	75	--	--	June 2	80	100	78
June 17	40	12	30	June 17	65	99	8
June 23	26	8	12	June 23	46	92	3
July 2	6	1	8	July 2	22	50	0
1968--May 28	99	92	98	1968--May 28	97	100	100
June 3	75	48	75	June 3	85	100	100
June 9	54	18	51	June 9	80	100	81
June 19	42	14	29	June 19	69	99	35
June 29	10	3	9	June 29	--	--	4
July 5	6	1	--	July 5	18	40	0
				July 13	4	6	--
1969--May 1	100	93	100	1969--May 10	92	100	100
May 15	94	82	93	May 15	86	100	91
May 25	75	54	76	May 25	74	100	40
June 4	50	19	40	June 4	58	96	6
July 2	11	--	--	July 2	6	14	0
1970--June 2	75	57	75	1970--June 2	90	100	100
June 19	41	--	29	June 21	66	99	32
June 24	--	--	22	July 1	39	68	5
July 1	11	5	9	July 15	1	2	0
1971--June 7	89	85	84	1971--June 12	85	100	88
June 12	79	69	76	June 23	57	93	27
June 23	37	21	36	July 8	16	34	5
				July 11	7	17	0

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Haeffner, Arden D., and Charles F. Leaf.
1973. Areal snow cover observations in the central Rockies, Colorado. USDA For. Serv. Gen. Tech. Rep. RM 5, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Photographic records of areal snow cover depletion during the 1964-71 snowmelt seasons in the Fraser Experimental Forest, and in the Park Range from 1966-71, are summarized. Included are detailed estimates of snow cover extent on more than 90 hydrologic subunits which comprise the six watersheds photographed. Applications of these data in streamflow forecasting, water balance analyses, and snow cover duration are suggested.

Oxford: 587:116.12. **Keywords:** Aerial photography, photogrammetry, snow cover, streamflow forecasting.

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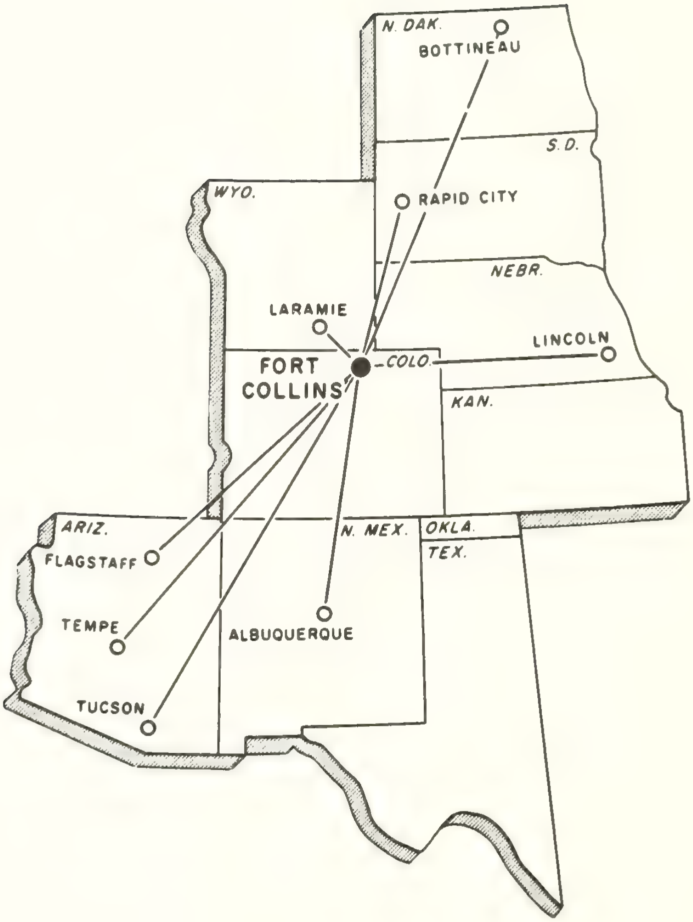
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Publications of the Rocky Mountain Forest and Range Experiment Station 1953-73

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USDA Forest Service
General Technical Report RM-6
September 1974

Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
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USDA Forest Service
General Technical Report RM-6

September 1974

Publications of the Rocky Mountain Forest and Range Experiment Station
1953-73

compiled by
Mona F. Nickerson, Technical Publications Editor
and
Glen E. Brink, Computer Programer

Station's central headquarters is maintained at Fort Collins, in cooperation with Colorado State University.

PREFACE

This list includes all publications of the Rocky Mountain Station since 1953. That year, the Southwestern Forest and Range Experiment Station was consolidated with the Rocky Mountain Forest and Range Experiment Station, and the combined headquarters was established at Fort Collins, Colorado. The Station's Annual Reports, issued each year until 1972, are not included in this list.

As the initial phase of a National information retrieval system for the USDA Forest Service, publications are listed alphabetically by author. The next phase will be a subject matter listing, with an annotation for each publication, and a cross-referenced index by senior and junior authors. Another phase of this project will be a complete list of all publications for both Stations, prior to 1953.

Periodical abbreviations are based on those of the American Standards Institute at the time this project began. All contributions by the same author have been listed together, although some articles were published with initials only, and others have used the given name.

Comments are welcomed in case corrections are needed before the subject matter list is published.

**Indicates an author who is either a private,Federal, or State cooperator.*

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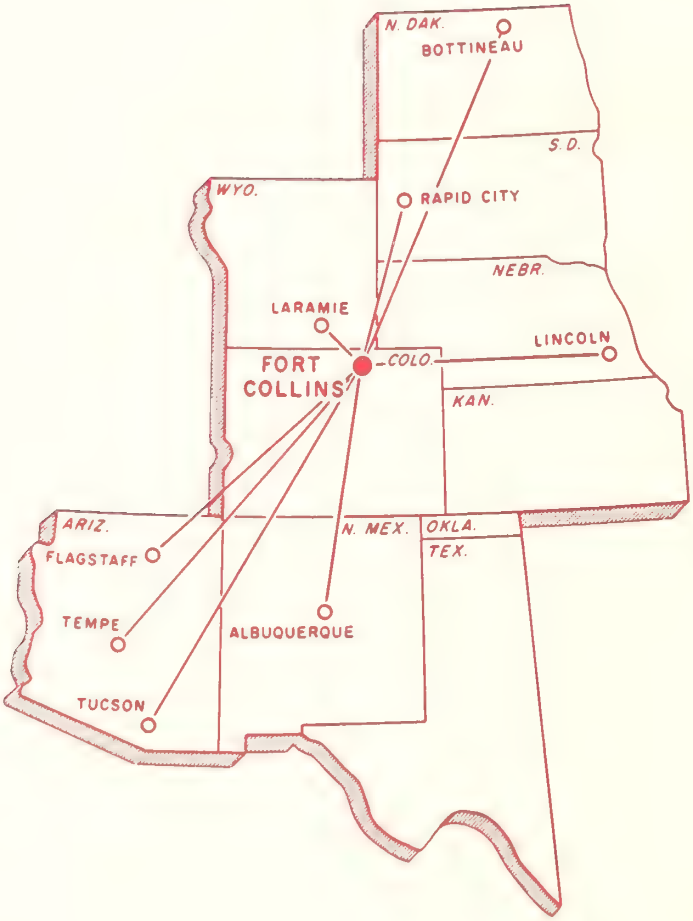
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Mountain Pine Beetle in Front Range Ponderosa Pine:

What it's doing and how to control it

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MOUNTAIN PINE BEETLE IN FRONT RANGE PONDEROSA PINE:

What It's Doing and How to Control It

Robert E. Stevens, Clifford A. Myers,
William F. McCambridge, George L. Downing,
and John G. Laut

Mountain pine beetle is currently in outbreak status in Rocky Mountain ponderosa pine stands. Much of the cause is probably related to the presence of extensive areas of susceptible forest. What to do about it depends on the objectives of the landowners or land managers. Combined programs using all suitable control methods are proposed.

Keywords: *Pinus ponderosa, Dendroctonus ponderosae.*

Ponderosa pine stands in the Front Range of the Rocky Mountains have a long history of mountain pine beetle infestations, and we are currently in the throes of a major outbreak. Several hundred thousand trees are being killed by beetles every year, and the end is not in sight. Public concern is high, and government agencies and citizens' groups alike are attempting to reduce the impact of the beetle outbreak by whatever means are available.

We have prepared this report to describe — as best we can — the conditions surrounding the current situation, and to suggest some practical means for prevention and control of beetle-caused tree losses. First let us briefly discuss some of the considerations:

1. **What are some of the reasons for the current bark beetle outbreak?**
   Two main things are required — a supply of insects and a supply of suitable host material. The beetles are ever present, but they only build up to outbreak proportions in stands in which most of the trees are at least 6 inches diameter at breast height or larger, and there is at least some overcrowding. Many of the pine stands in the Front Range are now in this category; hence, there is an abundance of suitable host material.

2. **What can we expect to happen if nothing is done?**
   Where nothing is done to help get the outbreak under control, we can expect losses to continue more or less at current levels. In general, the beetles kill trees in patches; patches will increase in size, but some stands and parts thereof will escape. Some areas not yet infested will be attacked; and the outbreak will subside in some of the heavily hit areas. Natural controls — primarily extreme low winter temperatures — may decimate local insect populations at irregular, often long intervals. The supply of susceptible host material will still be there, however, and infestation will recur in time.

Both trees and beetles have persisted for thousands of years, and there is no reason to expect total devastation of the ponderosa pine forests. Locally, however, tree killing has been, and will continue to be, severe in overstocked and marginal stands.

How the Beetles Operate

Mountain pine beetles have a 1-year life cycle. Adults fly and attack new trees in midsummer, usually July 15 to September 15. The beetles carry with them a bluestain fungus that hastens death of the tree. Successfully attacked trees die almost immediately, but do not fade for nearly a year. The beetles overwinter as larvae, and complete their development the following spring and early summer.

As we have noted, mountain pine beetles usually kill ponderosa pines in groups, rather than scattered single trees throughout the stand. These groups enlarge as subsequent generations of beetles continue the infestation, or new adjacent groups may be attacked. Groups may include from 2 or 3 to 100 or more trees. Infestations do not usually begin in trees under 6 inches d.b.h., but smaller trees are readily killed when an infestation is underway.

Management Objectives

The objectives of the land manager are critical to bark beetle control. They range from keeping every tree healthy and green, such as in a yard, to "letting nature take its course," or essentially no management whatsoever. Either, as well as intermediate objectives, may be reasonable under different circumstances. The manager must select an economic level at which to start some action; in other words, he must decide "How much loss can I tolerate?"

Approaches to Beetle Control

The first steps are to understand what to expect from the infestation, and to determine the management objectives. Knowing these two things, the manager can devise a rational plan.

Beetles do not respect land ownership lines. Dedicated work on one ownership may be wasted if infested neighboring forest is neglected. Thus it is usually necessary that work done be on a "community" basis. Individual, highly localized efforts — except in the case of individual tree protection, which we will consider shortly — are doomed to failure. In addition, it is most practical to begin a program before an outbreak has had much of a chance to get underway. Beetle populations are especially difficult to handle when numerous large groups of trees are becoming infested annually.

Four general approaches can be utilized: (1) direct control, using standard methods of burning (where applicable) or treating infested trees with an insecticide; (2) logging infested trees; (3) preventive silvicultural treatment; or (4) individual-tree protection.

The first two of these are well known and being generally used. Although the last two are not yet commonly employed in the Front Range, they may be extremely useful. Let us consider each separately, and then suggest how they can be combined in a "pest management" program.

Direct Control

Direct control is probably the best known and has been the most widely employed method of bark beetle control in the Front Range area. Insecticides (e.g. ethylene dibromide, lindane, cacodylic acid) are generally used, although in a few instances infested trees are felled, piled, and burned.

The purpose of direct control is to destroy beetles in currently infested trees before they can emerge and attack green trees. For direct control to be successful, all elements of the operation must be done properly: (a)delineating the area to be treated; (b) spotting infested trees; and (c) doing the actual control work — killing the beetles. A breakdown in performance of any of these three steps may mean that the project will fail. If an insufficient area is included, if infested trees are missed in spotting, or if trees are improperly treated, beetles will continue to develop and jeopardize the success of the operation.

Logging Infested Trees

This simply means harvesting currently infested trees. Beetles are then destroyed as a part of the sawmilling process. Obviously area delineation and spotting must be done as carefully in this approach as in direct control. Cutting infested trees for firewood is another aspect of the same approach. Infested material must not be left in the woods or in the woodpile when the beetles emerge, of course, or control benefits will be lost. Infested material should be burned or treated prior to beetle flight, which begins about July 15.

Silvicultural Control

Silvicultural control or "getting stands under management," has been recommended as a means to minimize bark beetle activity, but has been used little in the Front Range. The rationale behind this approach is to change stands that are in a "susceptible condition." In practice, this means thinning dense stands of trees of sufficient size to support an infestation.

In the northern Black Hills, outbreaks usually develop in those portions of stands with basal areas over 150 ft^2/acre, and with most trees over 8 inches d.b.h. Thinning to maintain stand density well below 150 ft^2/acre has been effective in suppressing a bark beetle outbreak in portions of the Black Hills where this practice has been carried out. Stands are thinned to a low enough density that they will not grow to 150 ft^2 before the next thinning.

In the Front Range, uniform pine stands are uncommon, but otherwise their characteristics are often similar to those in the Black Hills. Crown canopies are often closed or nearly so. Growth has slowed down. Thinning to open stands and stimulate growth should be as helpful in the Front Range as in the Black Hills as a deterrent to bark beetle outbreaks. Dense portions of stands 60 to 120 years old with an apparent potential for infestation (pure ponderosa pine or nearly so, most trees 6-8 inches d.b.h. or larger) will probably benefit from thinning to about growing stock level (GSL) 80. These thinning techniques are described in a Rocky Mountain Forest and Range Experiment Station research publication,[1] and are also discussed in a more general way in a paper currently in press.[2] Private landowners can consult local State Forest Service foresters for assistance in planning the proper thinnings.

There are two cautions to consider with regard to thinning: **First,** thinning obviously has no application in "fringe" areas, in which the trees may already be widely spaced. These are the areas where the forest meets the grassland, and both types of vegetation compete for dominance over long periods of time. Moisture is often critical for the trees, and frequently they are heavily infected with dwarf mistletoe. These stands are often susceptible to attack, and do suffer severe depletion under certain outbreak situations. Direct control and/or salvage is the only solution in these areas.

---

[1] *Myers, Clifford A. Field and computer procedures for managed-stand yield tables. USDA Forest Service Research Paper RM-79, 24 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 1971.*

[2] *Myers, Clifford A. Multipurpose silviculture in ponderosa pine stands of the montane zone of central Colorado. USDA Forest Service Research Paper (in press). Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.*

Secondly, it should also be recognized that the beneficial effects of thinning may be reduced if the thinned area is small and is surrounded by unmanaged forest in which an outbreak is permitted to go unchecked.

Individual-Tree Protection

We hope that research presently underway will soon enable us to recommend techniques to protect individual trees. This approach involves spraying a toxic material on the tree trunk to prevent beetles from attacking successfully. Such an approach will only be useful in situations where high value of individual trees justifies the expense of application. Currently, no insecticides are registered for this preventive type of use on live trees.

Techniques of the Future

Researchers around the world are working on a number of unconventional approaches to bark beetle control, some of which may, in time, become practical. These include use of repellents, or anti-feeding compounds, "sex attractants" (pheromones), manipulation of parasites, predators and insect diseases, and the like. At the present time none of these approaches is sufficiently reliable nor economical for practical application.

An Integrated Program

With the following integrated program, combining currently available direct and silvicultural control techniques, the land manager can greatly reduce losses to bark beetles. The program is based on two assumptions: (1) the manager wants to hold losses to a minimum, and (2) he treats a sufficiently large area to minimize serious beetle inflight from outside the area being treated. If he is willing to accept some stand depletion, a less vigorous program may be acceptable.

It will probably take 3 or more years to set up a management program to minimize losses caused by bark beetles if an infestation is underway. Tasks and an estimate of time necessary to accomplish them are as follows:

Year	Tasks
1	a. Determine boundaries of area to be included, and arrange for handling it as a unit. b. Salvage and/or direct control infested trees over entire area. c. Locate areas in which thinning is needed; begin thinning to about Growing Stock Level 80.
2	a. Continue salvage and/or direct control. b. Finish thinning.
3	Salvage and/or direct control.
4+	Maintain surveillance. Salvage and/or direct control, if needed.
10+	Reevaluate treated area. Thin when necessary to maintain low stand density.

Discussion

Proper implementation of a program should markedly reduce losses caused by bark beetles. However, it must be recognized that there is no way to reduce these losses cheaply, unless salvaged and/or thinned trees can be sold. The renewed interest in firewood in the Front Range will work in favor of bark beetle control, provided care is taken to prevent the spread of beetles from firewood to uninfested pines.

An important point is that the land manager must consider the bark beetle situation as a part of a larger overall picture, including **all** relevant biological and economic factors. For example, bark beetle control might not be advisable in a stand heavily infected with dwarf mistletoe, where the long-term outlook for the stand is bleak irrespective of the beetle problem. The land manager must always be alert to these related considerations.

Stevens *is Entomologist,* **Myers** *a Mensurationist, and* **McCambridge** *an Entomologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, with central headquarters at Fort Collins, in cooperation with Colorado State University.* **Downing** *is an Entomologist, USDA Forest Service, Rocky Mountain Region, Denver, Colorado.* **Laut** *is a Staff Forester, Insect and Disease Control, Colorado State Forest Service, Fort Collins.*

Technical assistance is available to help land owners and managers with forest pest problems. Contact your nearest U.S. Forest Service or State Forest Service office for further information.

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HE NOWY ORRENTS:

valanche Accidents in the ited States 1967-71

nox Williams

Abstract

Williams, Knox.
1975. The snowy torrents: Avalanche accidents in the United States 1967-71. USDA For. Serv. Gen. Tech. Rep. RM-8, 190 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

This compilation of 76 avalanche accident reports teaches by example, both good and bad. Commentaries will help those who spend time in the mountains in winter how to avoid getting caught in an avalanche, or if caught, how to survive.

Keywords: Avalanche, avalanche rescue.

About the cover: A soft-slab avalanche captured at the instant of release. Having triggered the slide, the skier is desperately trying to keep his balance and ski out to the side. Note the intricate pattern of cracks and the buckling of the slab as it fractures into large angular blocks. Photo by R. Ludwig.

USDA Forest Service
General Technical Report RM-8

March 1975

THE SNOWY TORRENTS:
Avalanche Accidents in the United States 1967 - 71

Knox Williams
Alpine Snow and Avalanche Project
Rocky Mountain Forest and Range Experiment Station[1]

> "The snowy torrents are like the deep sea;
>
> they seldom return their victims alive."
>
> From
> *Kampf über die Gletschern* (Battle over the Glaciers) by W. Schmidkunz

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[1] *Central headquarters is maintained at Fort Collins, in cooperation with Colorado State University.*

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PREFACE

Each winter approximately 10,000 avalanches are observed in the mountains of the United States. Many times this number fall but go unobserved. It is an unfortunate but immutable fact that man, his structures, and his facilities will be involved in a small percentage of these avalanches. The result is often terror, death, and destruction. Statistics compiled in recent years in the United States (based on data provided by the U.S. Forest Service Westwide Avalanche Network) reveal that in an average winter 140 persons are caught by avalanches, 60 either partly or wholly buried, 12 injured, and 7 killed. Also, an average of 30 vehicles are buried with 10 of these sustaining damage. In addition, 10 buildings, 2 ski lifts, and 7 to 10 miscellaneous structures or facilities are damaged each winter. Annual property damage by avalanches is roughly $250,000.

These statistics reveal the current magnitude of the avalanche problem in the United States. However, due to the rapid growth of winter recreation in this country, it is anticipated that these figures can only increase as time passes. The goal, therefore, is to keep the annual avalanche toll within a tolerable limit; the key to approaching this goal lies in public education. The range of this task begins with general avalanche awareness for the novice skier or snowmobiler and extends all the way to refining the skills of ski patrolmen and snow rangers. *The Snowy Torrents* is published as a partial fulfillment of this goal and is intended for an audience of skiers, climbers, snowmobilers, motorists, highway workers, cabin dwellers, mountain rescue teams, and a wide assortment of other interest groups.

This report is a compilation of 76 avalanche accidents that occurred in the United States from 1967 through 1971. It is a sequel to *The Snowy Torrents, Avalanche Accidents in the United States, 1910-1966* which was edited by Dale Gallagher and documents 63 accidents. The purpose of publishing these accidents is to teach by example—both good and bad. The experiences of many unfortunate avalanche victims can become lessons for us all.

Each accident report is concluded with a commentary. A strong effort has been made to treat the individuals involved in an accident—victims, survivors, rescuers —fairly. Wise and correct decisions and actions are praised: rash or unproductive actions are criticized with the intent of teaching the necessary safety procedures. Adverse criticism is aimed at pointing out lessons to be learned; obviously, there is no intent to embarrass any individual. The commentary section also serves to discuss some of the controversial subjects such as: avalanche zoning; "temperature release" avalanches; and hangfire or post-control avalanche releases.

It is also interesting to note the categories within which the 76 accidents of this report are classified. Thirty-five accidents occurred within ski areas: of these, 18 involved ski patrolmen or snow rangers performing their duties; and 17 involved recreational skiers. Ski tourers were involved in 12 accidents; climbers and hikers, in 11 accidents. Also included are four snowmobile-avalanche accidents and seven accidents involving either motorists, highway workers, or other workmen. Finally, there are seven accidents which damaged houses, cabins, or buildings, bringing death to the occupants in several cases.

Each accident documented is identified by a number that indicates the year, and the sequential number of the accident within that year. For example, No. 67-4 designates the fourth documented accident for 1967. This is the same numbering system used in the original *The Snowy Torrents,* and occasional references to accidents in that volume are made here. Beneath the heading is a statement of the toll of the accident; that is, the number caught, buried, etc. These terms are defined in the Glossary, Appendix 1.

Photographs and drawings are included with as many accident reports as possible. In the drawings, an open circle is used to indicate the final position of persons who escaped the avalanche or who were only partly buried; a solid dot indicates the final position of buried victims.

It is hardly instructive to study incomplete or inaccurate accident reports; consequently, only well-documented cases appear in this volume. Anyone involved in an avalanche accident is encouraged to provide thorough and accurate documentation if possible. Appendix 5 gives a sample of a complete information form for recording the details of an accident. Photos, maps, newspaper articles, and firsthand statements should be included whenever possible. A copy of the report should be sent to the Alpine Snow and Avalanche Research Project, Rocky Mountain Forest and Range Experiment Station, 240 W. Prospect St., Fort Collins, Colorado 80521. These reports will be compiled into future volumes of *The Snowy Torrents*.

At the end of this volume are five appendixes which include a glossary (Appendix 1); an explanation of the avalanche classification (Appendix 2); recommendations for avoiding and, if caught, surviving avalanches—all based on the experiences of avalanche survivors (Appendix 3); survival statistics for completely buried victims (Appendix 4); and an accident reporting form (Appendix 5). The information contained here should provide valuable guidance to safety-conscious individuals and rescuers alike.

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1 caught, buried, and injured

Weather Conditions

One foot of new snow containing .95 inch of water fell overnight on January 4 and 5 at Jackson Hole Ski Area. As the storm moved in, winds were moderate west-southwest and temperatures were in the twenties.

Accident Summary

On the morning of January 5, three Jackson Hole ski patrolmen—Richard Porter, Bob Sealander, and Kent Hoopingarner—skied down from the top of Rendezvous Peak and threw hand charges along their control route. When about half way down the mountain they began working the side of a deep gully, now called Dick's Ditch. Several hand charges were thrown along the upper end of the gully. Then Sealander made a high ski-cut and released a small surface sluff; he then skied around a hogback and continued his ski-checking. Porter skied underneath Sealander's cut, stopped, and then started to ski down the fall line. After his second turn, the slope fractured about 30 feet above him. A first-person account of Porter's ordeal taken from *Western Skier* magazine reveals his thoughts at the moment of being caught and then buried.

"I looked uphill and saw the snow hurtling toward me. There was no chance to out-ski the slide; I was knocked down almost immediately. I dropped my poles and began 'swimming' with it in an effort to stay on top of the snow. I finally came to a stop lying on my side, twisted around so that my feet were higher than my head. As the snow from above buried me, I managed to move my head around enough to form a small air pocket.

"The avalanche ended as quickly as it had begun. I could hear the muffled crunch above as the snow settled around me. It was solid, like being in a bag of wet cement. I couldn't move at all, but I wasn't uncomfortable. Oddly enough, I felt no sensations of cold, pressure, or even fear. . . just a cozy feeling of being all covered up with a thick, soundproof quilt. Even though I concentrated on breathing slowly to conserve the limited air supply, I soon lapsed into unconsciousness."

Rescue

Rescue began immediately. Hoopingarner climbed up to mark the last-seen point while Sealander skied to the base area. Within 11 minutes, a hasty search party of 15 men was organized and on the way up the tram. Arriving at the accident site, they searched likely locations at the area, finding no clues. A few minutes later the organized rescue party of 20 men arrived with packs, probe poles, and shovels. A probe line was established and worked up the slide area, not hitting anything. Hoopingarner thought the line had gone too far so they started back by his original mark. This time a probe pole hit a ski just a few feet from the last-seen point. Shovelling began.

After being buried 65 minutes, Richard Porter was pulled from beneath 5 feet of snow, gray, unconscious, and not breathing. Dr. Sam Southwick began mouth-to-mouth resuscitation immediately, then oxygen was applied. The victim began breathing again and was loaded into a snow cat and taken to the base area. To counteract the exposure he had suffered, he was stripped and placed in a tub of warm water. Later, in the hospital, intravenous fluids were given to counteract muscle cramps and blood poisoning resulting from oxygen starvation. Porter made a full recovery and was on skis again in 5 days.

Avalanche Data

The avalanche was classified as SS-AS-1: it was a small slide 120 feet wide and ran a mere 80 feet slope distance. It ran on an open slope having a south exposure and consisted of new snow sliding on an old snow crust. The slope was steep, nearly 40°, and ended in a deep gully; the debris from this small slide was extraordinarily deep.

Comments

When the control team entered Dick's Ditch, they had but one hand charge left, and it was being saved for another spot. In retrospect, that charge should have been used here. As an alternative, Porter should have continued his ski cut under Sealander's instead of stopping and then skiing down the slope.

Small slides are often the killers, and this avalanche very nearly proved fatal. The victim was swept to the bottom of the gully and buried deeply. Had he been buried many more minutes, he would not have survived. This incident provides evidence that, in a few cases, a buried victim has a better chance of survival with his skis on. The skis provide two more objects to be located by rescuers, and in this case, a ski was struck first by the probe pole. (However, the victim can swim with the slide more easily if skis and poles are cast off).

Richard Porter has these comments on his survival, again from *Western Skier* magazine: "I had a lot of time to think about why I survived for an hour, while other avalanche victims die in minutes. Fast, efficient rescue is the prime factor, but what goes on under the snow is important too. Making that air pocket undoubtedly saved my life. I'm in good shape physically and don't smoke so my system utilized the available oxygen efficiently. Having skied professionally for almost 10 years, I've become acclimated to the high altitude and cold. As a patrolman, I was familiar with avalanches and survival techniques such as making air pockets and breathing slowly. The fact that my head was lower than my feet helped blood circulation to the brain, while lying on my side prevented me from choking.

"I was lucky. A slight variation in any of these conditions and I probably wouldn't be alive to tell the story."

1 caught, buried, and injured; 1 vehicle buried

Weather Conditions

About 2 feet of snow had fallen during the 4 days preceding the accident. Temperatures were in the range of -10°F.

Accident Summary

On January 6, a crew of men working for the Star Valley Lumber Company of Afton, Wyoming were clearing the Smiths Fork Road of drifts to bring logging equipment out of the woods. The Smiths Fork Road is on Commissary Ridge, approximately 30 miles south of Afton. The men were trying to get the equipment out prior to more bad weather which was on the way.

At 0730 one of the men, Alvin Linstrom, was operating a bulldozer clearing the road of snow. He was working under a known slide area, an open slope with an easterly exposure. While the rest of the crew left for breakfast, Linstrom continued to work. Upon returning to the site, the crew discovered the whole area had been overrun by an avalanche. There was no trace of Linstrom or his bulldozer.

Rescue

For unknown reasons, there was a very long delay in reporting this accident to local authorities: the Forest Service in Afton did not receive the report until 1500. A check with the lumber company revealed that it was planning no rescue operation of its own, so the Forest Supervisor's Office in Kemmerer, 100 miles to the south, was notified.

At 1730 the Forest Supervisor returned from Ogden and was notified of the accident. By this time, rescue plans were belatedly underway. The Search and Rescue Unit, headed by the Lincoln County Sheriff, was planning to send a six-man party from Kemmerer in via LaBarge Creek, east of the avalanche site, at 0400 the following morning. The sheriff did not want to send the party in until daylight because of possible avalanche hazard.

At 2315, Bernard Linstrom, the victim's brother, called the Forest Supervisor. He was in Kemmerer with seven men—including several relatives of the victim—and all were equipped with snowmobiles. He said the sheriff would not send anyone to lead them in and none of them knew the country. He asked the Forest Supervisor if he would lead them to avoid further delay. The Supervisor agreed and left Kemmerer with this party at 0040 on January 7. Breaking trail in new snow and shoveling out a trail in one area slowed the progress of the rescuers; after almost 9 hours of travel they arrived at the accident site at 0930 on the 7th.

The Search and Rescue Unit left Kemmerer at 0500 and arrived at the scene at 1030. Their travel was much faster because the trail had been shoveled out and packed by the first party.

The initial rescue party was equipped with four 10-foot probe poles and immediately began probing the slide area at random. At 1000, Bernard Linstrom located the tractor by probing in a likely looking mound of snow. The top of the tractor was 5 feet beneath the snow surface. A few minutes later the victim, Alvin Linstrom, was found alive, still inside the canopy of the cat; he had been buried 26½ hours. Injuries sustained were a large bruise on the elbow, shock, and exposure. He was flown to the Afton hospital by helicopter and was released after examination.

Comments

Details on this accident are too few to draw any firm conclusions on the rescue efforts. It is not known whether a hasty search was conducted by the work crew shortly after the accident or whether the crew was equipped with a radio to send for help quickly. Even when the accident was finally reported in Afton, there was considerable confusion and delay in initiating rescue action. The helicopter used to evacuate the victim on January 7 might have been used on the 6th to get a rescue party to the accident scene while there was still daylight, weather permitting.

The considerable delay in getting rescuers to the scene nearly cost Linstrom his life. Fortunately the canopy on the bulldozer shielded him from much of the snow and provided an air pocket for breathing. However, even with adequate air, the victim may have succumbed to hypothermia had rescue been delayed much longer. Linstrom was indeed a very lucky man.

No. 67-3 Loveland Pass, Colorado January 7, 1967

7 caught; 1 partly buried and 3 buried; 1 injured; 2 killed

Weather Conditions

On January 4, Arapahoe Basin Ski Area, 2 miles south of the summit of Loveland Pass, reported 10 inches of new snow and temperatures well-below zero on the night of the 4th. Thursday, January 5, was clear, cold, and windy. Snow began falling again on Friday the 6th but its depth could not be measured because of high winds. Northwest winds of 50 to 60 m.p.h. blew much of the day on Friday and the extreme cold continued. Slab conditions were forming on lee slopes, and high avalanche hazard existed throughout the weekend.

Accident Summary

On Saturday, January 7, Herb Kincey, 32, took six boys from the Emily Griffith Home for Boys in Denver for a weekend winter camping and training trip. They were Dave Fritzler, 17; Don Porschatis, 17; George Davies, 17; Kenny Hunt, 15; Mike Anderson, 17; and Ken Landau, 17. Kincey was the Administrative Assistant for the Colorado Outward Bound School and was an experienced mountaineer. He had taken boys out from the Emily Griffith Home before and was leading this trip on his own time during the weekend.

Because of the low temperatures, special care was taken to adequately equip everyone. Each youth was issued warm clothing, climbing gear, and sleeping essentials. Group equipment included tents, stoves, cooking gear, food, radios, and other climbing and survival gear.

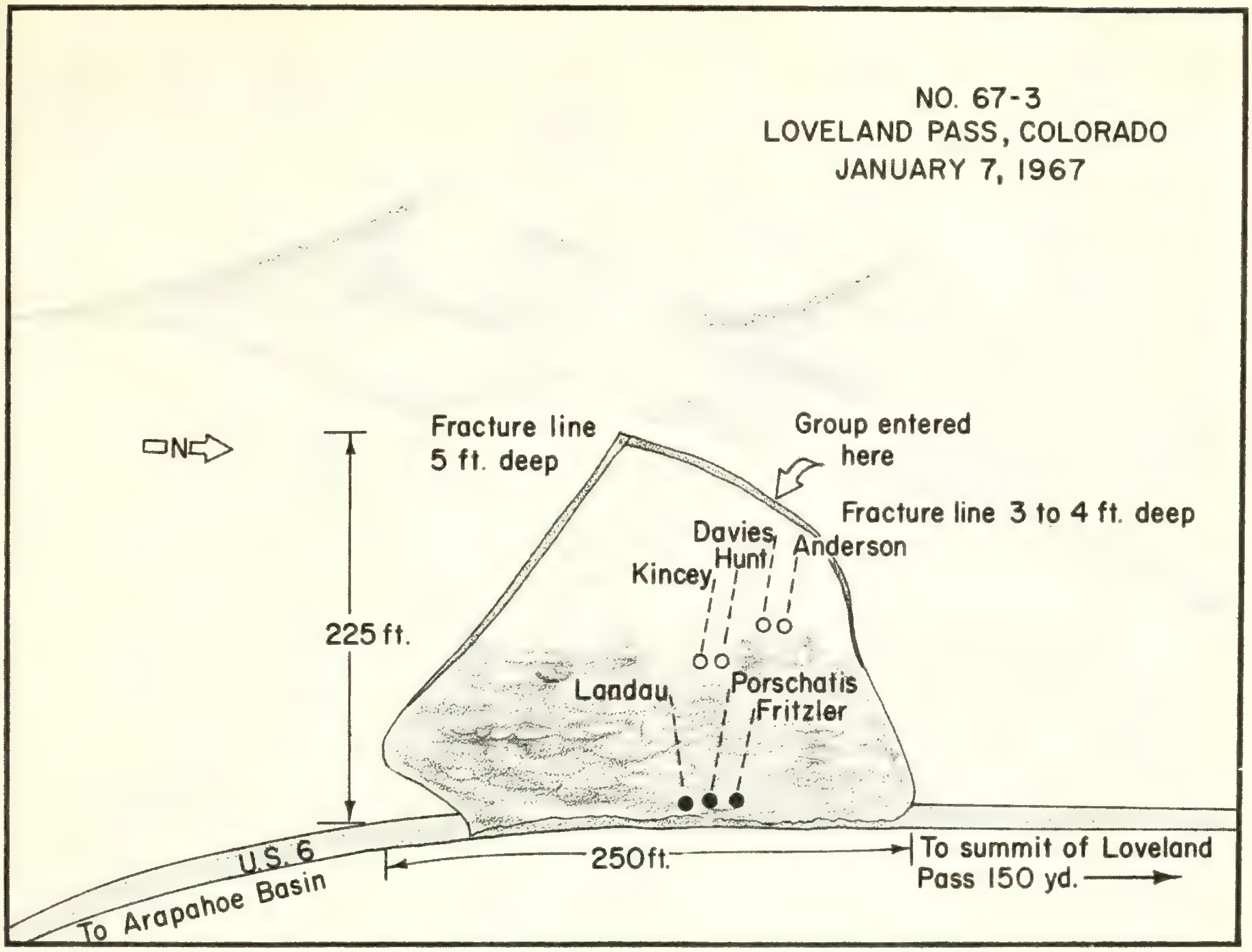
At approximately 1115 they reached Loveland Basin Ski Area; the leader decided to proceed immediately to the summit of the pass on Highway 6 before returning that night to camp in the valley near the Loveland Basin Ski Area. The wind was moderate, and it was sunny but cold at the summit (-3°F at the Loveland top lift at noon).

After parking at the summit and assembling their gear, the group made their way to the crest of the ridge 30 to 40 feet above the pavement just off the road on the west side of the summit. It was necessary to kick steps most of the way up, though in a couple of places they sank through the crust to soft snow about ankle deep. They continued along the crest, mostly on earth and rock, paralleling the road. Kincey examined several areas along the crest that might be used for glissading (sliding in standing, squatting or sitting position) and finally picked one about 150 yards up the ridge (Arapahoe side) from the top of the pass.

Their vehicle and a highway maintenance truck were parked in plain sight. The time was almost noon. The slope had an average slope of 27°, but was considerably steeper at the top and flat at the bottom, with a slight rising lip at the edge of the road. The snow surface was firm enough for glissading and the slope well located; a good runout at the bottom made it impossible for anyone to slide out onto the pavement. The ridge crest at this point was 100 feet vertically above the road, 200 feet away measured horizontally, and about 225 feet along the fall line.

Kincey stepped over the edge (there was no cornice) and tested the slope by glissading slowly down to about 30 feet below the crest, demonstrating basic glissading technique. The surface was firm enough to hold his weight without difficulty. The boys then spread out across the slope and began to glissade. Kincey stood at his point of arrest about 30 feet down, instructing and supervising. The boys had been on the slope about 10 minutes, glissading down and walking back up. Some of them had made as many as three runs.

Suddenly they heard a muffled boom. Kincey reported that he looked towards the highway to see if a vehicle had gone over the edge, but the sound was that of an avalanche releasing on the slope. The whole slope began sliding and all seven of the party were swept downhill. Because Anderson, Davies, Hunt, and Kincey were near the top of the slope when the snow fractured, they managed to stay on top of the moving snow. Landau, Porschatis, and Fritzler, however, were on the flatter part of the slope near the bottom, and the snow engulfed all three. They were carried over the snowplow cut and onto the road and were completely buried as the snow



poured over their heads.

Individual experiences during the avalanche were recalled the next day when the surviving members reconstructed the scene. Anderson was near the top, about 10 feet from the point where they had come down onto the slope; Davies was slightly below him and to his right. (All directions given are facing downhill.) Anderson reported that the snow he was standing on gave way and he began to slide downhill. He remained in an upright position; then a wave of loose snow began to engulf him, reaching up to the hips. He began to kick and worked his way up through the snow and fell on his back, head uphill. He came to rest lying mostly on top of several blocks of snow; he had been carried about 40 feet down the slope. Davies reported that he went onto his hands and knees, facing uphill, and rode the slide on top of a slab of snow. At no time was he covered by loose snow. He was carried about 50 feet and came to rest on a relatively flat area at the bottom of the slope, at least 100 feet from the road.

Kincey and Hunt were farther down than these two, and about 30 feet to their right. Kincey was instructing Hunt in the handling of his ice axe and in the proper sitting glissade position. Kincey was sitting and Hunt was standing beside him when the slide released. Hunt was knocked off his feet, and both he and Kincey were carried downhill riding on top of a slab of snow estimated to be about 18 feet square. Kincey shouted to Hunt to move uphill and swim if he was covered. Both attempted to crawl uphill on the slab. At no time were they buried in snow. They came to rest in the flatter area about 50 feet downhill.

None of these four persons, —Anderson, Davies, Hunt, and Kincey—were injured in the slide, and all took an effective part in the rescue.

The other three boys, Landau, Porschatis, and Fritzler, were standing at the bottom of the slope, in the runout, where it was not steep enough to glissade. Landau had just done a sitting glissade diagonally down from the center of the slope to the right; he crossed below Kincey and Hunt and came to rest in the flatter area of the slope. He stood up and was looking up at the others when the snow he was standing on began to heave up and down. Then he was hit by a wave of snow that knocked him down backwards, and he recalled sliding toward the road on his back, head downhill. Snow covered his face, and he felt he was choking with snow with every breath. Then he rolled over on his stomach, fought with his arms, trying to push up on the snow. He slid over the slight lip on the edge of the road and was dumped down onto the road. He soon felt a second impact, the weight of snow dumping down on top of him, pushing his face into the snow and pinning his arms beneath him. Landau recalled that he shouted three times for help, said a prayer, and passed out.

Porschatis and Fritzler had just completed their third slide, a sitting glissade in the track just below Anderson and Davies. They had come to a stop slightly below Landau. They were laughing and talking to each other. Apparently they were still in a sitting position, facing downhill toward the road, when the slide started.

Kincey reported seeing two boys (they were all wearing orange parkas) lifted up by a wave of snow and carried toward the road. They disappeared as they fell onto the road and were covered with snow.

The whole slide probably lasted no more than five seconds. A triangular area 250 feet across at the base and 200 feet long (approximately 100 feet vertical) had come loose. Snow, 6 to 7 feet deep, covered the highway.

Rescue

When the slide stopped, three boys were safe—Anderson, Davies and Hunt—and three could not be seen—Landau, Fritzler, and Porschatis. The survivors heard three shouts for help and called back, but got no reply. Kincey organized search operations immediately. He and the three boys probed in the snow with their ice axes for a couple of minutes in the approximate area of where shouts had been heard. Leaving the boys to continue probing, Kincey then ran 150 yards uphill to the summit of Loveland Pass to seek help. The men in the highway maintenance truck parked there had seen the slide and had already radioed for help, requesting avalanche poles, a doctor, and a search party.

Cars were stopped on both sides of the slide, and skiers and passers-by began to gather at the slide scene. Kincey asked some of those in the immediate area to recruit rescuers from the lines of cars; those equipped with ski poles and shovels began probing the avalanche debris. This began in a haphazard fashion. Kincey then organized them into a line that moved from the road uphill through the slide area. Some continued to probe at random. The highway maintenance crew was among the first to join in the search. A state highway patrolman was there within 5 to 7 minutes. Within 10 minutes, 60 to 70 people had stopped and joined in the search; this group included Dr. John Bohannan (a Special Forces doctor from Ft. Bragg, N.C. who was a passenger on an eastbound bus) and an unidentified nurse.

It took 15 to 20 minutes to find the first victim, Dave Fritzler, under about 4 feet of snow. As soon as he was spotted, Kincey told Davies and some spectators to get the litter, sleeping bags, clothing and first aid kit on the trailer at the top of the pass. Fritzler was not breathing and had a very weak pulse. Anderson, one of the survivors who had previous Outward Bound training, began immediate mouth-to-mouth resuscitation. Dr. Bohannan supervised the operation, giving directions. Moved to the road, Fritzler was laid on sleeping bags, covered with another, and given cardiac massage. Others rubbed his hands and feet. This was continued for about 45 minutes, under Dr. Bohannan's supervision, until Fritzler began breathing on his own. He was then given oxygen provided by an unidentified person.

Ken Landau was located next about 5 minutes after Fritzler was found. He was lying on his stomach, face in the snow, arms pinned below him. It was necessary to dig his arms out even after his body was uncovered. His feet pointed diagonally uphill. He likewise did not appear to be breathing when pulled from the snow. The nurse immediately began mouth-to-mouth resuscitation. Landau was moved to the road, placed on bags, and given cardiac massage. He began to breathe without assistance in about 20 minutes and was then given oxygen.

Don Porschatis was found last, about 5 minutes after Landau. He was lying face down, head uphill, feet toward the road. At this time (1230) the hasty search party from Loveland Basin Ski Patrol arrived and proceeded to dig him out. Even before he was totally uncovered, mouth-to-mouth resuscitation was begun. Porschatis began to breathe on his own in about 20 minutes, and he too was then given oxygen. All three boys were found within 20 feet of each other in a line along the edge of the road just below the cut made by the snowplow. All were buried beneath about 4 feet of snow.

After the boys were extracted from the snow, Dr. Bohannan took charge and supervised their revival. Passers-by formed teams and applied mouth-to-mouth resuscitation, cardiac massage, and rubbing of hands and feet. At 1240 the main party of the Loveland Basin Ski Patrol rescue party and the Forest Service District Ranger arrived with additional emergency equipment and oxygen.

When the victims were breathing 14 times a minute, the doctor advised moving them. Since Landau appeared to be in the best shape, he was placed in an ambulance that had come up from the Arapahoe side and taken to the clinic in Dillon. The next day he was moved to Denver and returned to the Emily Griffith Home where he was then hospitalized for observation to avoid possible pneumonia. He soon made a full recovery.

The other two victims were in worse shape. After their breathing rate was up to 14 per minute, Dr. Bohannan advised moving them to the Loveland Basin Ski Patrol infirmary. They were transported in the ski area's station wagon and another car volunteered by a by-stander. There they were placed under the care of Dr. Fowler, the medical officer in charge.

Before leaving the scene of the slide, the ski patrol and Forest Service personnel insisted on checking names and numbers to ascertain that all persons were accounted for. Only when this was done, did they leave.

At Loveland Basin, Dr. Fowler placed Fritzler and Porschatis under resuscitators, one that he had and another that was brought up from the Idaho Springs Fire Department. They were later transported by two ambulances to St. Anthony's Hospital in Denver accompanied by pro patrolmen. The victims had difficulties on the trip in. One stopped breathing briefly and had to be revived with the resuscitator. Although the oxygen ran out on the other, he continued to breathe fairly normally. Both had convulsions during the trip, and neither regained consciousness. They were admitted to the emergency room at St. Anthony's Hospital and treated immediately; both were in critical condition and suffering from anoxia (effects of having been without oxygen).

Both boys suffered irreparable brain damage from anoxia; Porschatis died 4 days later, and Fritzler finally succumbed several months after the accident.

Avalanche Data

This avalanche was classified as HS-AO-2. In this case, the slide was triggered by the weight of the climbing party on the slope. The slope had sustained the weight of the climbers for several minutes before failure occurred. The hard slab had formed from the recent snow and strong winds; snow depth was 3 to 5 feet in the lee of the ridge but much of the windward side had been blown bare.

Fracture-line depth was 5 feet at the apex of the slide and 3 to 4 feet where the party was training. The slide ran only 100 feet vertically, but a large volume of snow was moved. The debris contained many large blocks of snow. Beneath the slab was several inches of depth hoar which had formed in the shallow snowpack earlier in the winter. Contributing to the danger of this slide path was the cut bank above the highway. The avalanche filled in this bank and resulted in all three victims being deeply buried.

Six of the Seven Sisters avalanche paths had run the day before, January 6. These had been shot down with artillery as part of the avalanche control on the Loveland Pass highway. Avalanche hazard was definitely high.

Comments

Kincey was a good leader and was experienced in climbing techniques and winter survival; however, he apparently did not consider the possibility of avalanches, or he misjudged the stability of the snowpack on this day. Two mistakes were made, one in planning and one in judgment.

First, a review of the preparations for the outing shows it to have been carefully planned except for one omission—no avalanche emergency equipment! They were properly clothed for winter weather and their equipment included suitable camping equipment, emergency gear, hard hats, first aid kit, 2-way radios, and a litter. However, had the boys been wearing avalanche cords, recovery of the buried victims might have been quicker. (Avalanche cords should not be trusted too highly; they also can end up completely buried.) Furthermore, no probe poles were included in the emergency gear. The omission of both these items suggested that an avalanche mishap had not been considered.

Second, an error in judgment was made by taking the group onto the slope without having checked on current avalanche conditions. Knowledge of the conditions was available at Loveland Basin and Arapahoe Basin ski areas. Both areas were concerned and had blasted slopes on Friday and Saturday. Avalanche danger was unusually high. Snow slides came down in Loveland Basin in places where they had never been seen before. Had Kincey inquired about local conditions, he might have been warned and might have canceled the trip.

In addition, had he known the area better, he would have known that the chosen slope had a past avalanche history. However, the slope did appear safe, but deceptively so. It was not overly steep nor was it long. There was a flat runout at the bottom. The surface was tested and it was hard, but deeper probing with probe poles or ice axes would have revealed the weak, cohesionless layer. Further deception was added by the nearness of the highway. It was felt the group was safe even in the event of mishap because their vehicle with all of their emergency equipment aboard was only 150 yards away.

Once the tragedy struck, emergency procedures were carried out well. Kincey reacted excellently under stress and instantly assumed leadership of the rescue. He initiated a hasty search and within minutes had sent for help. Also he organized the passers-by into a search party that systematically probed for the victims. The medical care they got was outstanding, considering the conditions. The ski patrol and U.S. Forest Service personnel at both Loveland Basin and Arapahoe Basin showed a remarkable state of readiness.

Despite signs warning of avalanche dangers, this slope and the surrounding bowls continue to be popular ski-touring terrain, mainly because of the easy access. These circumstances virtually insure that more skiers or climbers will fall victims to avalanches in this area sooner or later.

11 caught; 5 partly buried and 3 buried; 2 injured

Weather Conditions

The weather on Sunday, January 15, was clear and reasonably warm for January in the Wasatch Mountains. The temperature in the Alta parking lot at 0930 was 24°F. Winds were gusting between 15 and 20 m.p.h.

Several days earlier, strong northwest winds had built up considerable wind slab at higher elevations. On Saturday, several avalanches were shot down at Alta, and several more were brought down at both Alta and Brighton on Sunday. The avalanches at Brighton, however, were much larger than those at Alta, signaling a higher instability in the Brighton area.

Accident Summary

A party of 13 skiers assembled at Alta on the morning of January 15 for a ski tour that would take them over Flagstaff Ridge and end at Silver Fork Lodge in Big Cottonwood Canyon. Before leaving, one member of the party called the Forest Service to check on avalanche conditions. He was told that the slab conditions created by recent west and northwest winds were still present. There was no widespread avalanche danger, but there was a very definite localized danger on high, lee slopes due to the heavy wind drifting during the last two days. He was also advised to stick to the ridges as much as possible and to avoid any deep drift pockets on lee slopes.

This was a group of well-experienced, well-equipped Wasatch Mountain Club members. All had experience in ski touring, but to different degrees. Two of the members had recently taken the National Ski Patrol Circle A Avalanche Course, and another member had received first aid training. The group's equipment included adequate clothing and food, climbing skins, avalanche cords, six avalanche probes, six first aid kits, and an Austrian portable toboggan.

The group climbed to the ridge, reaching it just west of Flagstaff Peak. Avalanche cords were used on the steeper slopes, but snow conditions appeared to be stable along the route that was followed. Party members were advised to maintain a reasonable separation during the climb.

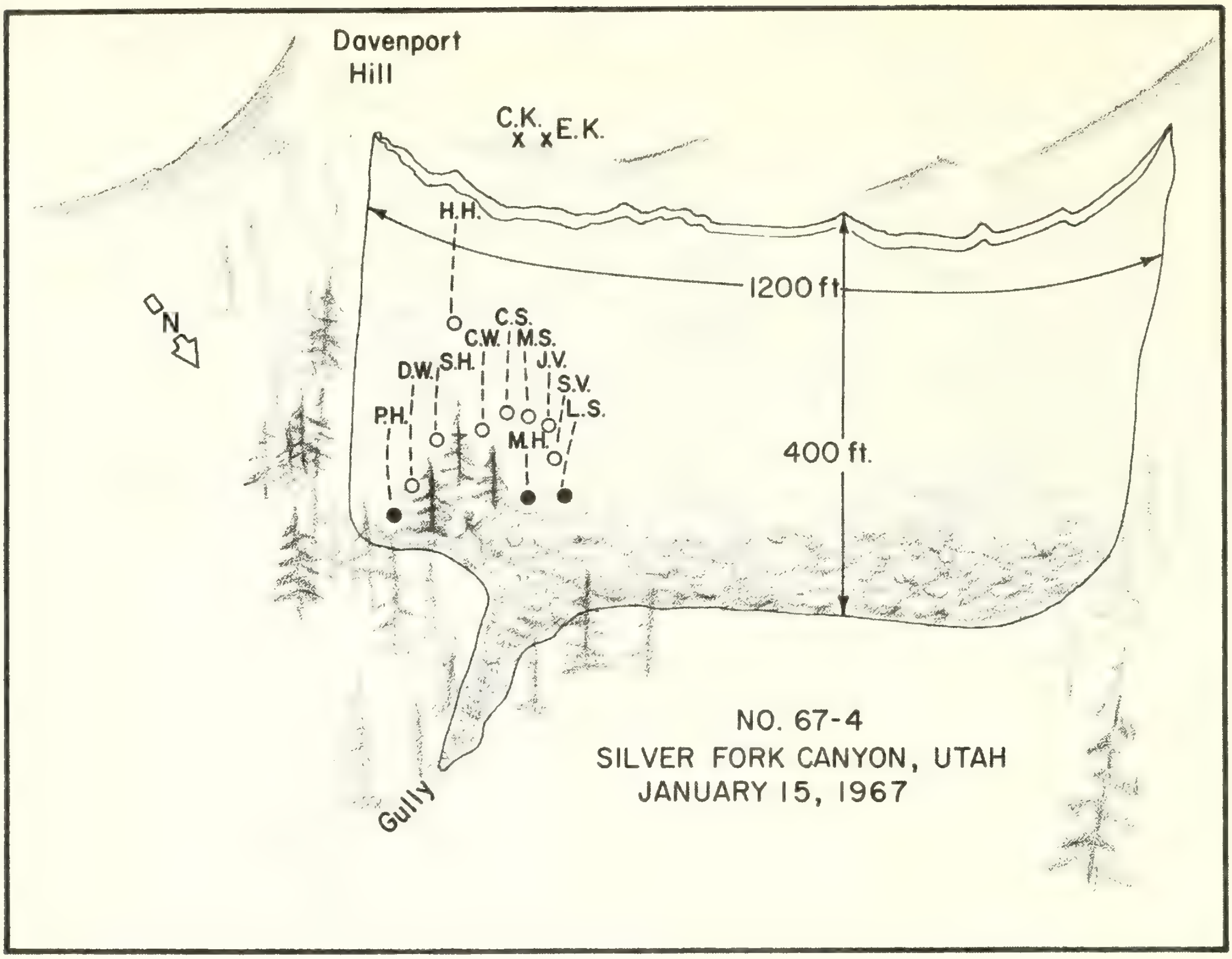
Once on the ridge the group traveled toward the east. Snow conditions varied from loose and reasonably light in wooded areas to extremely hard crust in the open areas. Except when traversing around Flagstaff Peak and around another minor peak about a half mile farther east, the group remained on the ridge. At the lowest point on the ridge above the head of Silver Fork, the group stopped for lunch.

The Silver Fork slope directly below the point where the group ate lunch faces a northeasterly direction. This slope, as well as those to the left (west) were devoid of trees. However, to the right (east) were several clusters of fairly large trees. To gain the protection of this vegetation, and to get farther away from the lee slopes of the recent winds, it was suggested that skiers who preferred not to ski down the fall line take a traverse to the right (east) toward the trees. The time was 1430.

Two of the first three skiers to leave the ridge, Milton Hollander and Lee Steortz, skied straight down; the third, Peter Hovingh, went to the right a short distance and then straight down. Several others left the ridge and headed to the right. Then, as if the enthusiasm to ski suddenly struck the group, all but two, Charles Keller and Ernest Katten, of the remaining skiers left the ridge. One turned to the left (west) and four others followed. They had proceeded 40 to 50 yards and were skiing very close together when the shot-like sound of the fracture was heard. The snow on the slope immediately broke into large slabs and began to slide. Of the two remaining on the ridge, only one, Keller, was able to witness the entire slide. It was impossible for one person to keep track of 11 people below. When the snow stopped sliding, the location of more than three or four of them was very uncertain. The five who had skied to the left (west) remained standing during most of the slide, but when three of them finally fell, they were lost from view.

Rescue

Because the fracture was just several feet



below the very small cornice on the ridge, it was not felt that further slide danger existed from above. Thus, as soon as the snow stopped sliding, the two men remaining on the ridge (Keller and Katten) started down, looking for people or equipment on the way. About 100 feet down the slope one ski was found; its owner, Hermann Haertel, was found clinging to a tree about 20 feet below. He was in considerable pain and claimed his right leg was broken. His left ski, still secured to his boot, was removed and, together with both skis belonging to Keller, was placed in the snow below him so he could relax without rolling down the slope. He was left there while the search for survivors continued. Keller went down to the point where several people were digging for Hollander who had been completely buried except for one hand, while Katten went to assist another group.

When the snow stopped sliding, a group of seven skiers—Hollander, Steortz, Steve and June Viavant, Carl Schwenk, Max Townsend, and Carol Wiens—were bunched together. Steve Viavant, who found himself on top of the snow, saw a hand. He started to dig and found Hollander. Hollander immediately asked if anyone else was buried. Viavant looked around and saw another hand nearby. He dug there and found Steortz. June Viavant had also remained on top of the snow. She helped Schwenk, Townsend, and Wiens who were all buried to depths ranging from knee to waist deep. Keller arrived about the time Steortz's head was uncovered and helped dig Hollander out. As soon as he was free Hollander helped dig out Steortz, while Keller headed for another group, counting heads on the way.

Once the snow had stopped sliding, Hovingh, Delbert Wiens, and Suzanne Haertel had been thrown together. Wiens found himself free on top of the snow. Haertel was buried to her waist to the west of Wiens. Hovingh was completely buried, but when he opened his eyes he saw light. He shouted for help. Wiens, who was almost overhead, heard him and started digging. Katten arrived on the scene from the ridge and helped Suzanne Haertel out of the snow, and then helped Wiens dig for Hovingh. Keller, who was counting people, found all accounted for and helped dig Hovingh free.

By the time all people were out of the snow, it was determined that one man (Hermann Haertel) had a broken or badly injured leg, another (Steortz) had a sprained ankle, and three (Hollander, Hovingh, and Steortz) had lost one ski each. Knowing that additional help could be used to take the injured man out and that the three men with single skis could probably use help, three people (Katten, Delbert, and Carol Wiens) were sent down to advise the sheriff and ask for aid. They left about fifteen minutes after the avalanche, about 1445. They arrived at Solitude Ski Area at 1630 and reported the accident to the ski patrol who, in turn, notified the U.S. Forest Service.

While the three men who had been buried probed for their lost skis (they did not find them), the rest of the party climbed back up the avalanche slope to the injured man. He was suffering intense pain, so much so that it was doubtful that he could be moved while in that condition. He was given a Percodan capsule, a pain relieving drug that was carried for just such an emergency. His skis and poles were used to assemble the emergency toboggan. By the time it was ready, the capsule had taken effect, and his spirits and morale had improved considerably. All excess clothing —mostly sweaters—were used to wrap his injured leg, and it was lashed to his good leg with climbing skins and secured by straps. He was then placed in the toboggan and the cover laced over him. In this position, his injured leg was completely immobile. He was taken from the avalanche slope by four men. At the bottom, they tied four ropes to the toboggan and the long trip down to the Solitude Ski Area began. The time was approximately 1520.

At this time two of the men who had been buried, and who had only one ski each (Hollander and Steortz), were sent ahead so that they could move down Silver Fork at their own pace and attempt to get to the highway before sundown. They arrived at the Solitude Ski Area at 1845.

All party members were at Solitude by about 2130 after a difficult trip. After the injured man reached the hospital and X-rays were taken, it was found that he had no broken bones. Several torn ligaments were repaired in a subsequent operation, but he was still left with a badly damaged nerve in the leg. The latter accounted for his intense pain on the avalanche slope.

Avalanche Data

The slope on which the avalanche occurred was open and steep (about 37°) and had a northeasterly exposure. The avalanche was classified as SS-AS-4. The entire slope avalanched, being some 1200 feet wide and running a vertical distance of about 400 feet. The 11 skiers who had triggered the slide and who were caught were concentrated in the eastern one-third of the slope.

When the slope failed, there was the loud shot-like report and then the slab shattered into large pieces, some large enough that three skiers remained on top of the snow. The fracture line varied from 4 inches deep to more than 1 foot. Although much loose, light snow was involved, there was no dust cloud, allowing Keller on the ridge above to follow visually many of the skiers as they were trapped. The three men who were completely buried were well below the fracture line when the slide began; the five others that were partly buried were nearer the fracture line.

Comments

In all, 11 skiers were caught in the Silver Fork avalanche; 8 were buried, and 2 injured. Fortunately for the three completely buried victims, they were very near the surface; two had one hand showing and the cries for help of the third were quickly answered.

The snow and avalanche conditions reported to the group by the Forest Service that morning proved to be quite accurate. The Silver Fork slope was on the lee side of the ridge and was an area of localized danger because of wind slab. Shooting reports from Alta and Brighton that came in after the group had left revealed, however, that the avalanche danger was greater than had been suspected, especially near Brighton.

It can be concluded that two factors were primarily responsible for the avalanche. First, the number of people on the slope at one time was excessive; second, the suggestion that several of the skiers ski to the right (east) to gain the protection of the trees was not heeded. The fact the avalanche extended about 50 yards to the east and 300 yards to the west of the entry point on the ridge, and the decrease in slab thickness toward the east, suggests that had everyone gone toward the right (east), the avalanche might never have been triggered.

3 caught and partly buried; 1 injured

Weather Conditions

The early part of the winter of 1966-67 at Alta, Utah was characterized by large storms followed by periods of clear weather. In mid-October, a snowstorm dropped 21 inches of snow in the area. A clear period followed and the snow melted off the southern exposures, but patches remained on north-facing slopes. In mid-November another storm left 2 feet of snow on the ground for the winter. The November storm was followed by several days of cold, clear weather, and a tendency toward depth-hoar formation was noted on north-facing slopes. The snowpack gradually built up until mid-December, at which time there was a period of warm, clear weather.

During January 1967 an unusually large amount of snowfall was dropped by the storms that came in rapid succession with only brief breaks separating them. Throughout the month there were only 8 days when no precipitation was measured. One of these interludes occurred on January 18. On the afternoon of the 19th, the winds began to gust up to 30 m.p.h. from the southwest, and clouds filled the sky. It became apparent that a major storm was coming.

Little snow fell on the 19th and the 20th, but the winds continued blowing strongly from the southwest. On January 21, snow began to fall in earnest, and the wind gained intensity. The winds became so strong that day that the Germania chairlift was closed. It was noticed that north- and east-facing slopes were becoming loaded with drifting snow. The temperature was steady at 20° to 25°F throughout the day.

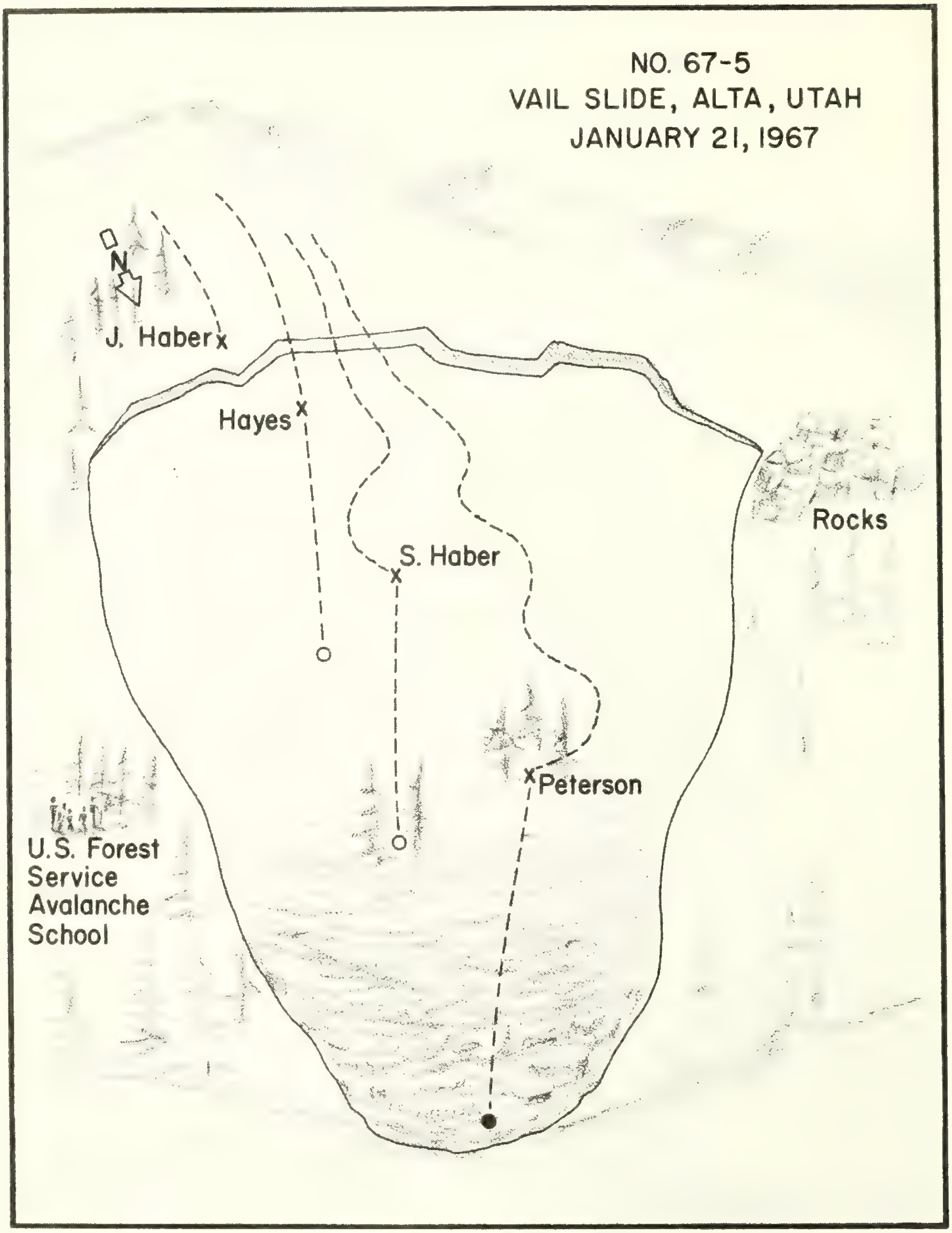
Accident Summary

During the period from January 18 to 28, the U.S. Forest Service was conducting its biannual avalanche school at Alta for Forest Service personnel. The field session for the afternoon of the 21st involved snow-profile studies on the mountain. The original plan was to dig snow pits to check the stratigraphy up high on the mountain in the release zones of some of the larger slides in the area. However, the closing of the Germania lift caused a change in plans. It was decided to carry out the field work on the ridge below the Albion gun tower, just west of the top of the Albion ski lift.

Leader Ed LaChapelle took the avalanche trainees to an area off the ridge and just east of a short slide path. There they dug a snow pit that revealed 21 inches of wind-deposited new snow overlaying slightly decomposed fine-grained old snow. Below the fairly solid old snow was a weak layer in which equi-temperature metamorphism had taken place. Underlying this layer was 6 inches of weak depth hoar capped by an ice crust. The depth hoar was probably formed after the early October storm, and the ice layer formed during the period of warm weather prior to the November storm. The layer of equi-temperature metamorphism crystals (ET crystals, for short) reflected the clear period following the November storm.

Snow Ranger Ron Perla was in the snow pit explaining the stratigraphy to the trainees. When he found the depth hoar, he decided that conditions were highly unstable. He asked the more experienced LaChapelle for his opinion, and LaChapelle said that he agreed strongly with Perla's diagnosis. The avalanche occurred almost immediately after these comments.

Meanwhile, shortly after 1500, four skiers— Bill Peterson, Steve Haber, Robin Hayes, and Janie Haber—departed from the Albion lift and headed out Never-Sweat Ridge in search of untracked powder. The four were expert skiers, the two men being ski instructors from Vail,Colorado. The closing of the Germania lift had eliminated some of the better powder snow runs; therefore the four decided to look for a challenge off the Albion lift, basically a beginner and easy intermediate area. The party skied out the ridge to a point just west of the route the Forest Service personnel had taken. Upon reaching the top of the short, steep slide path off Never-Sweat Ridge (now named the Vail Slide) they stopped momentarily; then Peterson skied about halfway down the slope, stopping next to some small trees. At this point, members of the avalanche school heard him calling out to the


NO. 67-5
VAIL SLIDE, ALTA, UTAH
JANUARY 21, 1967
N
J. Haber
Hayes
S. Haber
Rocks
Peterson
U.S. Forest
Service
Avalanche
School

others in the party, telling them to ski on down. This was the first that the avalanche school knew of the group's presence on the slope. Steve Haber and Hayes immediately started down the slope, Haber in the lead. As he was making a hard jump turn to the right about one-quarter of the way down, the snow fractured above him; this carried him, Hayes, and Peterson down the hill. The fracture line was about 150 feet above Peterson, 35 feet above Haber and 15 feet above Hayes at the moment of release. As the three people were being carried down the hill, LaChapelle directed the avalanche school trainees to follow them with their eyes. One skier was seen to enter a small clump of trees and moments later emerge down the slope. The descent of Hayes was easily followed because she stayed on the surface.

Rescue

As soon as the slide came to rest, the Forest Service personnel marked the last-seen points and began a hasty search of likely areas. One of the trainees immediately went up the hill to a point about 90 feet below the fracture line, where Hayes had come to rest. She was found to be unharmed, though hysterical.

When the avalanche broke, Perla was still in the snow pit. He jumped out immediately, mainly for fear that he would be buried in the pit and only secondarily to aid in the rescue. Nonetheless, he ran toward the moving avalanche, following the path of Peterson who was being carried down the slope. Hence, Peterson was located almost immediately near the toe of the slide by a protruding ski tip. He had come to rest on his back, face up, head downhill, and had managed to clear the snow from around his face as he came to a stop. His legs were buried under about 3 feet of snow; and his head was about 18 inches below the normal snow surface but not covered because of its position between two blocks of snow. His arms were pinned down by his ski poles which were still on his wrists, but he was uninjured and calm when found.

Minutes later groans were heard near one of the small trees about two-thirds of the way from the top of the slope; here, Steve Haber was located. He was found with his head downhill, lying mostly on his side. While being carried along in the slide, he was forced against a tree, with his right ski passing on one side of the tree trunk and his body on the other. The force of the snow had thus put a great amount of force on his right leg. Although he was wearing safety bindings, they were over-tightened and did not release; his right leg was badly broken at boot-top level and was somewhat displaced, causing him severe pain. His legs were under about 40 inches of snow; his head was about 18 inches deep but free of snow because of protection by tree branches.

As Haber was being dug out of the debris, the Forest Service personnel were informed by one of the victims that there were four people to account for in the slide, and probing was immediately resumed for the remaining victim. At this moment Janie Haber appeared at the top of the slope, safe and unharmed. When she had seen the slide release about 5 feet below her, she immediately jumped back to a tree at the top of the slope and had remained hidden there while the other victims were being accounted for. She was very calm, although she later began to show some signs of shock.

As soon as the avalanche occurred, two men were dispatched by LaChapelle to pick up probe poles and a toboggan from the top of the Albion lift. After all victims were accounted for, another man was dispatched to inform the lift operator that no probes were needed. Steve Haber had been dug free and his leg splinted by the time the toboggan arrived. He was evacuated to the ski patrol first aid room at the base of the Wildcat lift pending the arrival of an ambulance from Salt Lake City. At 1620, the ambulance arrived and he was transported to a hospital in Salt Lake City. All rescue operations were secured at 1630.

Avalanche Data

The slide occurred on Never-Sweat Ridge, a fairly short northeast-facing slope and a known slide area. The slope has now been named the Vail Slide in dubious honor of the Vail ski instructors who became the victims. At the release zone, the slope angle is 41°; it flattens to 22° at a transition zone below. The avalanche was classified as SS-AS-3, was 40 yards wide, and ran 120 yards slope distance. The zigzag fracture line was 8 inches deep on the east end and 30 inches deep on the west. The sliding surface was discovered to be an ice layer with a layer of weak ET crystals above and depth hoar below.

Comments

This is the type of accident that is difficult to prevent. With a storm in progress, avalanche hazard was increasing as the day wore on. Dangerous areas were being closed as the intensity of the storm increased, but no closures were in effect along Never-Sweat Ridge.

Because of the strong southwest winds, a condition of instability arose in just a few hours; the Vail Slide should have been either closed or checked for safety. This slope is now ski checked and hand charged during and after storms. However, ski checking is pushing one's luck on this slope; it deserves hand charges.

No. 67-6 Twin Lakes Pass, Utah February 11, 1967

2 caught, 1 buried

Weather Conditions

A very cold fall with light snowfall and a thin snow cover caused the early season formation of depth hoar in the higher Wasatch Mountain areas. December 1966 brought normal snowfall plus two rain storms which produced hard sliding surfaces in the snowpack. Above-normal snowfall was recorded in January 1967, along with exceptional wind action.

Early February in the Alta and Brighton area found the weather generally clear and mild. Snow depth at Alta measured 105 inches. On February 10, a storm moved in and deposited 6 inches of new snow, most of it falling as graupel. Strong northwest winds gusting to 40 and 50 m.p.h. accompanied the storm.

February 11 broke clear and mild with moderate northwest winds. Afternoon cloudiness brought a trace of snow. Temperatures ranged from 12° to 26°F.

Accident Summary

At noon on February 11, two experienced skiers, Jack Gordon and Rex Anderson, left the Brighton Ski Area to ski tour Twin Lakes Pass to the west. They got off the top of Mt. Millicent lift and skied outside the ski area boundary without notifying anyone or inquiring about snow conditions. The selected route exposed them to extreme avalanche danger the entire way. They did remove their pole straps from their wrists, but their arlberg straps were left tied down on their skis.

Snow Ranger Will Bassett was standing on the ridge overlooking the Twin Lakes Pass area and the Brighton Ski Bowl when he observed the two men traversing across the hazardous avalanche area. Remarkably, he then observed the avalanche as it was released by the two skiers; the time was 1315. The snow fractured 80 yards above the men, and they were quickly engulfed by the slide.

Gordon was carried 200 yards downhill by the slide and buried just below the surface with his face up and head downhill. He was able to get an arm free and clear his face. Anderson was carried approximately 120 yards in the slide and remained on the surface.

Rescue

When the slide stopped, Anderson discovered that he had lost one ski and one pole. Nevertheless, he started downhill looking for Gordon and found him buried but unhurt. Anderson was able to dig out his companion.

Not knowing that the skiers were unhurt, Snow Ranger Bassett reported the accident to the Brighton Ski Patrol at 1320. He then took three patrolmen and immediately headed for the accident scene. Seven minutes later a second hasty party of five patrolmen left with probes, marking flags, and a shovel. Several minutes later, the main rescue party of 10 men left for the scene, fully equipped.

At 1340, the first hasty party led by Bassett was in voice contact with the two victims and was assured that everything was all right. Anderson's missing ski was found, and they were able to ski out. The second hasty search party was stopped 300 yards from the accident site to prevent them further exposure to avalanche hazard. The main party was stopped ½ mile from the site. The back-up rescue party was then disbanded, and the ambulance that had been called was canceled. By 1430, the rescue effort had been completed and secured.

Avalanche Data

The avalanche occurred about 1½ miles west of the top terminal of the Mt. Millicent chairlift at Brighton. The slope has a northeast exposure and an average steepness of 30°. It has a history of sliding after most new snowfalls.

On February 11, the day of the accident, an identical exposure in the ski area was checked by artillery fire at 0800. It did not slide. However, estimates of avalanche danger were that the hazard was increasing during the day. Touring was closed on the 11th.

The avalanche was a SS-AS-3, approximately 100 yards wide and running about 300 yards slope distance (450 feet vertical). The fracture line was 2 feet deep for most of the width of the slide.

Comments

The accident reports do not state whether the two victims had crossed under any closure ropes or passed any closure signs. However, the area was closed to touring. The victims neither checked on avalanche conditions nor notified anyone of their plans. Had they done so, they would have learned of the hazardous conditions and of the closure.

Had Gordon been buried deeper or had he not been able to clear his face so quickly, this avalanche may have taken his life. The good fortune of the snow ranger being an eyewitness to the accident made for a quick rescue, had it been needed. Failure to check weather and snow conditions and failure to observe closures are two sure ways of risking one's life in avalanche terrain.

2 caught; 1 partly buried and 1 buried; 2 killed

Weather Conditions

The Pharoahs Glen area is only a few air miles from the Twin Lakes Pass area of Utah. The same storm described in No. 67-6 also struck the Pharoahs Glen area, depositing dense graupel pellets and buffeting the hillside with very strong, gusty winds. On Saturday, February 11, the winds recorded at the Salt Lake City Airport averaged 37 m.p.h. The prevailing direction was northwest. Winds diminished on Sunday but were still gusty.

Accident Summary

At 0530 on Sunday morning, February 12, three boys left the Eastwood Grade School on Wasatch Blvd. on the east side of Salt Lake City. They were Dick Bills, age 15, his brother Tom Bills, age 14, and Bill Dubbeld, age 12. Their destination was Grandeur Peak, about 2 miles to the east and located between Mill Creek Canyon and Parley's Canyon, through which runs U.S. Highway 40. All three boys had considerable hiking experience in this area but no formal mountaineering experience.

Just before 1100, they reached the summit of Grandeur Peak and built a fire. After eating, they started down, jumping and playing on the north side of the peak at the head of Pharoahs Glen. Dubbeld dropped his canteen which rolled down the slope, and he slid down after it. After retrieving his canteen he had difficulty climbing back up the slope. He finally called to his friends that he wanted to walk on down and come out the bottom of the canyon. The other two boys consented and started down the slope. The time was about 1130.

Dubbeld had gone about 50 feet down the hill; Tom Bills was above him and Dick Bills was another 50 feet farther below him. Suddenly Tom Bills shouted "Avalanche!" But Dubbeld was engulfed just as he turned to look uphill. He was swept downhill and into a large pine tree, holding tightly onto a branch until the snow stopped moving. When the slide was over, Dubbeld found himself buried to the waist and still clinging to the tree. He was able to dig himself out while Tom, who had remained above the slide, worked his way down the slope. There was no sign of Dick.

After a quick search of the area, Dubbeld left the slide site and headed down a northwest ridge to U.S. 40, several miles away. Tom Bills remained at the scene searching for his brother.

Rescue

At about 1330, Dubbeld reached the highway and flagged down a motorist. A few minutes later, the accident was reported to the State Highway Patrol and the County Sheriff. The Sheriff's office in turn notified the Brighton and Alta ski areas. Ski partolmen and Forest Service personnel began heading for the Eastwood School, where a base for the rescue operation was established. A helicopter was called to transport the rescuers to the slide scene.

The first rescuers were flown to the scene at 1525. The helicopter continued to take rescuers in by two's until there were 42 at the site. Probes, shovels, and other supplies were flown in with the rescuers. Because of the size of the rescue party, there was considerable confusion in coordinating the rescue effort. In addition, the rescuers did not know how many victims they were searching for or where to search for them. The sole eyewitness, Dubbeld, was flown in the helicopter over the slide area to determine the places where he had last seen his companions. By this time, Tom Bills who had remained at the accident scene, could not be found. Because Dubbeld was not closely interrogated by the rescue party leader, the rescuers did not know whether there were one or two buried victims or whether Tom had also walked away from the scene.

The rescuers began by probing deep deposition areas and by setting up a coarse probe line at the toe of the debris. Footprints were seen going down Pharoahs Glen below the toe of the slide. Some of the rescuers thought these tracks should be followed, but the decision was made to continue probing.

The coarse probe revealed nothing, so a fine probe was begun at about 1900. The probe line had moved about 200 feet up from the toe of the debris when the body of Dick Bills was found approximately 6 feet under the snow; he was lying in a prone position, head downhill. The boy's scout pack was on top of his head with both straps still on his shoulders.

The entire body was encased in an ice mask, a little heavier thickness around the face, but the opinion of the rescue group was that the boy was unconscious when he came to a stop. It was apparent he was bleeding slightly from either the nose or mouth, or both.

The snow was removed from around the body with fire shovels. The snow was too hard for the aluminum snow shovels to penetrate to any degree. Approximate evaluation of survival time was no longer than 30 minutes. The victim's right arm could be straightened out, but the left arm could not—it remained in a bent position.

While the probe line was searching for this buried victim, a report was issued over the radio that the other missing boy, Tom Bills, had been found safe on the ridge. This report was false, and no explanation for the error could be found. Fortunately, this report did not reach several of the rescuers who had become curious about the footprints leading down Pharoahs Glen. Six men began following the footprints. About ¾ of a mile below the toe of the slide debris, a hat and then a pair of socks belonging to Tom were found. Sixty feet from where the hat was found, Tom was found lying on his back in the snow. The time was about 2100. He was not breathing, and there was no heartbeat. Mouth-to-mouth resuscitation was given but to no avail. Tom Bills had died a victim of shock and hypothermia.

The bodies of both victims were flown out by helicopter at about 2300. Rescue operations were ceased at this time, and the main rescue party began walking out via Pharoahs Glen to U.S. 40. The last rescuer was checked in at the base camp at 0315 on Monday morning, February 13.

Avalanche Data

The slide was a soft-slab avalanche starting at an elevation of 8100 feet and running to 6500 feet, a vertical drop of 1600 feet. The width was 300 feet at the starting zone and 150 to 200 feet in the runout gully. The fracture line was only 4 inches —4 inches of soft slab that had been deposited on a one-inch-thick layer of graupel. It slid approximately 150 yards on this surface and then started to break away underneath. At about 200 yards, it dug right down to the ground level. A snow pit showed 8 inches of depth hoar right at the ground. In addition, the ground cover consisted of long grass bent downhill. The combination of the hoar and the grass provided a slick running surface.

The slope was on a north exposure and had a steepness in the starting zone of 33°. There was a 5-foot snow cover in the starting zone and track. Rescuers found a lot of evidence of avalanches in past years: shrubbery and trees were very sparse, and those in the slide path were markedly scarred up.

Comments

The rescuers erred by not questioning the survivor more closely and by not putting him back on the ground at the slide scene. Had he been brought back to the scene, he could have identified his own tracks leading down the ridge to the highway. The rescuers would have then known that the tracks leading down the gully below the avalanche debris were those of the other missing boy, Tom Bills. When Tom was found, he had been dead only a very short time. With better information, the rescuers could have begun following his footprints hours earlier. This action might have saved his life.

The critical need to obtain all possible information, and the consequences of failure to do so, are evident in this rescue effort. Apparently because of the boy's youth and the feeling that he had been through enough already, he was not closely interrogated. In retrospect, it is clear that the information he could have provided was vital to his companion. In addition, given the confusion that existed at the rescue scene, the rescue leader should have taken the initiative much earlier to question the survivor further and to check out the footprints. When all the facts are not known, all possible clues should be investigated thoroughly.

This accident was the fourth in a small area of the Wasatch Range in less than a month (see Nos. 67-4, 67-5, 67-6 also). The weather of the last few weeks—either heavy snow, strong winds, or both—kept hazard high by perpetuating slab formation. In back-country areas, a steep, uncontrolled, north-facing slope should always be suspect. In this case, the evidence of past avalanches was a further sign that this slope was dangerous. The key to eliminating accidents of this nature lies in education: the general public needs to be taught avalanche safety techniques and the identification of dangerous avalanche terrain.

16 caught; 14 partly buried; 2 buried and killed

Weather Conditions

At the time of the accident on February 18, the sky was overcast and a 15 to 20 m.p.h. north wind was blowing. A noticeable drop in temperature had occurred shortly before noon as a storm moved into the area, bringing intermittent snow flurries.

Accident Summary

A Circle A Avalanche Training Course was being held at Skyline Ski Area near Bonneville Peak about 20 miles east of Pocatello, Idaho. Instructors and enrollees of the course met Friday evening, February 17, for 3 hours of instruction on how to recognize signs of avalanche hazard, how to minimize danger, and how to travel through hazardous areas. Instruction was also given on practices to follow if caught in an avalanche.

On Saturday morning, the 18th, the party included Kieth Longson, the instructor, and the 30 members of the Circle A Avalanche Training Course. The group was scheduled for a practical exercise simulating the rescue of an avalanche victim.

During this morning session, the trainees received instruction in snow stratification and in techniques of probing for avalanche victims. While this was going on, another instructor, John Laffoon, and a local ski patrolman went to Green Canyon, a known avalanche area, where they buried a straw dummy. Laffoon and his companion buried the dummy in a deep snow deposit. Before leaving the site, the whole area was tested by shovel and skiing with no evidence of instability. After lunch, the entire group assembled at the bottom of the ski hill and awaited the simulated witness report that would mark the start of the exercise.

Upon getting the witness report at 1400, a hasty party of 11 people equipped with probe poles was organized and sent to the simulated avalanche area. The hasty party entered the area from the east, above the heavy snow deposit, arriving at 1435. Meanwhile, a main party was being organized at the base area to follow the hasty party.

The hasty party flagged a trail into the simulated avalanche area. One man was posted as avalanche guard. The others probed on the face of the snow deposit and, after a few minutes, found the dummy. Instructor Laffoon told them to leave it buried so the main party could also carry out the simulated search-and-rescue exercise.

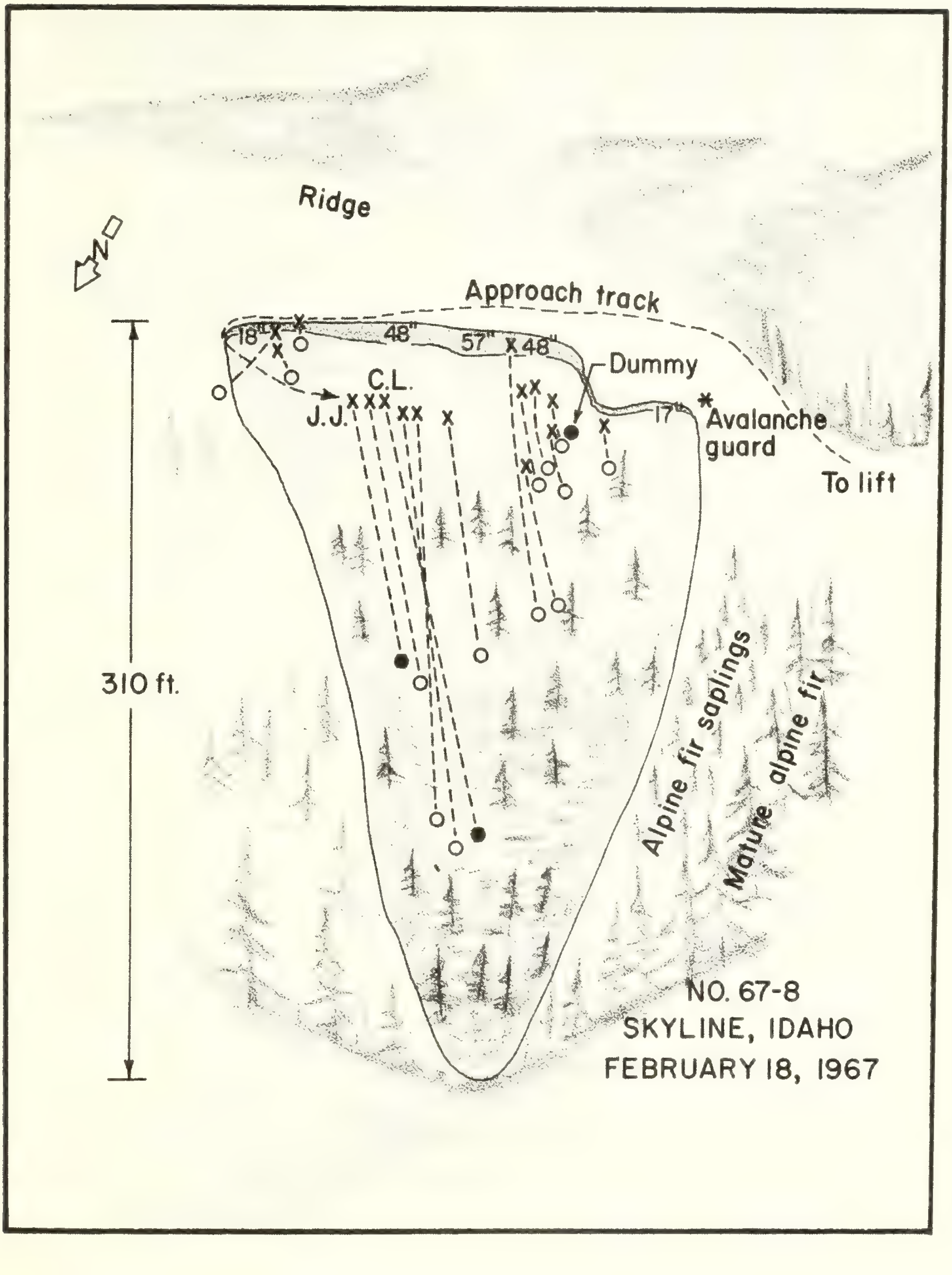
While the hasty party had been probing, the avalanche guard discovered a crack in the snow above the group and called this fact down. Immediately, Herman Torrano, one of the probers, climbed to the ridge to check on the crack. (The crack was an old glide crack which had been in evidence for nearly 2 months. It had been observed repeatedly by members of the ski patrol who shovelled and rounded the cornice weekly.)

By this time, members of the main party were arriving. This party had gathered their equipment and left the top of the chairlift at 1438 and arrived at the simulated avalanche area at 1445. Art Hendricksen, Skyline Ski Patrol Leader and leader of the entire rescue exercise, was with the main party. When he arrived at the site, he began organizing the party into crews of five and sent them into the avalanche area to probe for the "victim." He accompanied the first crew.

Meanwhile, Torrano called instructor Longson over to look at the crack. Longson looked over the edge at the probers below and became alarmed for their safety. He then made the decision to clear the area of all personnel.

He mentioned this to one of the main party but did not have time to relay this decision to leader Hendrickson. At 1450, just minutes after the main party had entered the slope, the snow suddenly fractured above the group. (The accident report does not state whether the fracture line coincided with the preexisting crack.) Sixteen members of the group were caught and swept downhill for distances ranging from only 20 feet to more than 200 feet.

A head count was started immediately. About 5 minutes elapsed before those at the



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top learned that two people were missing. The lack of a feminine reply to the head count indicated Carolyn Laffoon (wife of John Laffoon, one of the instructors) was missing, and the fact that John Johnson was known to be in the slide area but couldn't be located identified him as the other victim. While the head count was in progress, those who were caught in the slide were digging themselves out or helping dig out others who had been caught.

The force of the slide left probe poles bent and wrapped around trees. Avalanche cords were being used by members of the followup group but these were broken both by the force of the slide and by being swept through the trees. John Laffoon had his skis on and was standing in the southwest corner of the area when it slid. One ski was broken on his short downhill ride.

Rescue

Additional probes, shovels, ropes, and a toboggan had been called for by radio and were on the site or on the way. An avalanche guard was named for the rescue effort, and searchers were sent into the area. A hasty search was conducted with searchers probing likely spots for the two victims, mainly around and under trees. This search located the first victim, John Johnson. He was buried between 2 and 4 feet deep in the center of a group of saplings. His head was downhill nearly 4 feet under the surface of the avalanche. The snow was so compacted it was difficult to remove it from around his body. He was lying more or less on his right side. Some snow was packed in his eyes, nose and mouth. Mouth-to-mouth resuscitation attempts were begun at 1542 by Dr. Jim Sullivan. Closed chest cardiac massage was also used throughout these attempts but there was no sign of life. He was pronounced dead at 1547. Cause of death was listed as cardio-vascular failure resulting from suffocation. Johnson had no ice mask and there were no signs of attempts to free himself. He was removed from the area by toboggan at 1600 by members of the class.

The hasty search failed to locate Carolyn Laffoon, so a coarse probe was started. One coarse probe line was started at the bottom of the slide and another line was organized about 170 feet uphill from the bottom of the slide. After 15 to 20 minutes of probing, the lower probe line located the victim under 5 feet of tightly compacted snow. She was found at 1650 and was checked immediately by Dr. Charles Sternhagen. Her body was cold, face was blue, and there was no pulse. She was pronounced dead at 1705. Cause of death was listed as cardio-vascular failure resulting from suffocation. There was a slight ice mask formed by body heat. At this point, all personnel except those working with the second victim were cleared from the area. The body of Carolyn Laffoon was removed from the scene in a Stokes litter by members of the rescue party.

Avalanche Data

This was a hard-slab avalanche classified as HS-AS-4. The fracture line was 220 feet wide and varied in depth from 18 to 57 inches. The slide carried 310 feet down the slope, becoming wedge-shaped and narrowing to 25 feet wide at the bottom.

The slope was a known avalanche path but was an infrequent slider. It faced north and was very steep, about 40°. The snow fractured at an elevation of 8050 feet. The slab was a very dense and compacted layer of wind-packed snow. Just below was a soft, cohesionless layer. A test pit had been dug on an adjacent slope at 1130. The stratigraphy was evident to the instructors, but they decided there was no immediate slide area.

The ridge top above the slope had a low brush cover. The slide area itself contained numerous trees; these were second-growth subalpine fir with diameters of 3 to 6 inches.

Comments

The lesson to be learned from this accident is obvious: simulated rescues should not be carried out on a known slide path unless the snow is known to be stable. In this case, three things may have lured the instructors into a false sense of security. First, even though the crack was present in the snow, some may have felt that, since the slope avalanched only infrequently and it hadn't failed this winter in spite of the crack, it was safe. Second, the presence of the tree cover may have indicated to those in charge that the slope couldn't slide. It should be noted that only a dense stand of timber can anchor snow to the slope, and the steeper the slope, the more closely spaced the trees must be. Third, the high-density hard slab found in the snow pit had probably convinced the instructors that failure could not occur in spite of the loose snow below. Indeed, the hard slab probably would have supported one or just a few skiers indefinitely. However, under the combined weight of no fewer than

16 skiers, the load was excessive and failure occurred.

Hard slab is a more difficult medium to work with than soft slab. The toughness of the slab often gives every indication of stability: test skiing is seldom effective on hard slab. A quick pit should be dug to determine the depth of the slab and what sort of layers lie underneath. If any doubt exists, explosive control should be used. No explosives were used on this avalanche slope. This protective measure might have brought down the avalanche, thus revealing the danger and preventing the loss of two lives.

7 caught; 3 partly buried and 1 buried; 1 injured

Weather Conditions

One of the most popular runs at Alta, the Ballroom, is located under the east face of 11,068-foot Mt. Baldy. Skiers entering the Ballroom are threatened by several chutes that make up the east face. There are three types of hazards. First, the chutes are high-frequency avalanche paths themselves. Second, cornices form over the chutes and huge cornice blocks when released can travel down the chutes into the Ballroom. The third hazard involves falling cornice blocks which can trigger chute avalanches.

On March 22, 1967, the Alta snow rangers blasted the Baldy cornices. A hard-slab avalanche (HS-AE-3) accompanied the release of these cornices. In the past, one blasting operation per ski season had been sufficient to clear the cornice hazard.

The subsequent weather pattern was unique for the Alta area. There were 20 days of precipitation between March 22 and April 21 producing 111 inches of new snow and a water content of 10 inches. The snowfalls occurred mostly at night and at low temperatures (the mean low was 20°F). The April sun formed crusts rapidly during the day. The precipitation was ushered in by strong westerly winds, and the Baldy cornices were rebuilt to a hazard level. Six avalanches, ranging in size from 2 to 4, fell from Mt. Baldy in this period.

Accident Summary

At 0600 on April 21, the Alta snow rangers were advised by their supervisor (stationed in Salt Lake City) that he was coming up to direct the blasting operation of the re-formed Baldy cornice. Because of an unfavorable mountain weather forecast, the snow rangers expressed some reluctance to go on the mission but eventually consented when pressed by their superior. At 0730 the 75-mm pack howitzer was rolled out of the Forest Service garage, and four shells were fired below the cornices on the east face of Baldy. No slides occurred; the regions below the cornices were judged to be stable.

At 0900 a party of four men began the mission. In the party were Snow Rangers Ron Perla and Bengt Sandahl (inexperienced in cornice blasting); Ray Lindquist, their supervisor (experienced); and Chris Berry, an Alta ski patrolman. They left the top of the Germania lift and climbed to the summit of Mt. Baldy. They carried dynamite for 35 blast holes, a hole driller, and a Forest Service radio for communication with the Germania lift foreman. The summit was reached at about 1000. A decision was made to keep the Ballroom open while the cornice was being prepared for blasting. The ski run would be closed when the charges were ready.

Perla was instructed to move on a drilling line within 6 feet of the edge of the cornice and to drill 7-foot-deep holes spaced 9 feet apart. He noted that his drill was puncturing through the cornice, and he could see light through the hole. This was mentioned to Lindquist, but his only reply was that this happens occasionally in cornice drilling.

Perla was being belayed by Berry who started in a secure sitting belay position with a new 5/16-inch "Goldline" climbing rope. This was Berry's first attempt at belaying; he was very inexperienced.

The predicted bad weather moved in; the workers' toes and fingers became cold. To speed up the operation, Lindquist was belayed by Sandahl and joined Perla on the cornice. Sandahl was an experienced mountaineer and belayer. Lindquist had tied in to the other end of the 5/16-inch rope, the only rope available. All four members were essentially joined by one 5/16-inch rope!

Berry, affected by the cold, went into a standing belay position. Perla had drilled 23 of the 45 planned holes; Lindquist, following on the cornice, had filled these holes with dynamite. The time was 1120, and Perla was drilling his 24th hole while Lindquist was tying prima cord to the 23rd hole's charge. Perla and Lindquist had by now moved to a precarious position for their present belay.

Suddenly, the cornice collapsed! The fracture ran along the line of drill holes. Perla and Lindquist were straddling the drill holes and went down with the cornice. Lindquist's belay held, and he was left dangling at the lip of the cornice. Perla's belay did not hold, and he fell along with the cornice into one of the larger Baldy chutes. The chute fractured and a size 5 hard-slab avalanche poured down on the Ballroom. Several skiers were in the Ballroom at this time.

The pressure of the moving debris against Perla's body was sufficient to snap the 5/16-inch rope. He was sent on an incredible 1500-foot ride. For the three others in the group, the rope snapping was a fortunate occurrence; the belayers were being pulled toward the brink, and the whole party would have fallen into the chute.

Perla describes his experience: "The cornice broke, and I waited for the belay to hold. It didn't, and I was in the chute. There were strong pressures against my body. The rope broke, and I was on my way. I knew it was a large avalanche. I tried to make swimming motions. The force of the snow against my face closed my eyes. The amount of time I was in motion seemed to go by quickly, and I sensed coming to rest. Next, I thought only of the snow piling on top of me, the amount of which would determine my survival chances. I realized I was face up. I tried to place my left hand over my face, but the piling up snow forced it away. However, before the snow set up, I was successful in getting my right hand up through the snow. The piling up of the snow ceased. I knew my hand was out of the snow and that I had excellent chances. I then tried to conserve air awaiting rescue, but almost immediately blacked out—the experience seemed painless, except for a firm pressure against my chest making it difficult to breathe. Returning to consciousness was a gradual process. At first it seemed I was able to breathe through the snow, then I saw figures standing above me. Finally, it became clear that the rescuers had found me and had opened an air space around my face. A slight headache due to anoxia and 3 days of stiffness were my only physical disabilities." (X-rays taken several years later for another illness revealed several vertebrae had been broken in the victim's back.)

Rescue

After losing his belay on Perla, Berry rushed to the aid of Sandahl. Together they were able to bring Lindquist up to safety.

At this time it was feared that several people, including Perla, were buried in the extensive debris. Lindquist shouted initial rescue instructions to skiers in the Ballroom area below and then began transmitting requests by radio for rescue assistance. A Forest Service dispatcher received Lindquist's message at 1130 and relayed the information to the County Sheriff. Three ambulances, a helicopter, and auxiliary rescue equipment were dispatched to the scene.

In the deposition zone below, a skier noticed Perla's outstretched hand, and with the help of another skier, uncovered Perla, who had been buried for about 2 minutes. He was evacuated to Watson Shelter, and given a doctor's examination. Three other skiers partially buried in the slide were also quickly extricated.

Lindquist remained on top of Mt. Baldy to secure the loose explosives. Sandahl skied down to the Ballroom to organize a hasty search operation for possible victims. The time was 1130. Sandahl coordinated the procurement of rescue equipment from the nearby Forest Service caches. A snow cat was used to deliver the equipment which included probes, shovels, marking tape, wands, four toboggans, and two oxygen bottles.

About 150 skiers assembled at the debris to volunteer for probe-line duty. A large percentage of these volunteers were ski patrolmen and ski instructors visiting Alta for the I.S.I.A. clinic. Lindquist skied down from the top of Baldy to supervise the logistics of the remaining rescue operations.

Four coarse-probe lines were formed to comb the massive deposition area, and eye-witness accounts were compiled to establish the possible number of buried victims. Witnesses confirmed that seven people were involved in the slide: Perla, the three who had been partially buried, and three others who had skied off without any help.

All seemed to be accounted for; however, one witness reported having seen two additional skiers caught in a deep deposition zone near the toe of the east end of the slide. On the strength of this witness' account, Sandahl organized a fine probe line of 60 volunteers to probe the area in question. The fine probe was begun at 1400, required 2 hours, and was not able to locate any trace of a victim. Throughout the duration of the search process, food and hot beverages were delivered to the volunteers by various Alta concessionaires.

Also, the County Sheriff and Forest Service personnel had been actively gathering and tracing down all possible missing persons. Road blocks were set up. Lodges were asked to account for all their guests. Parking lots were checked. All people in the Alta area were accounted for by 1630.

Avalanche Data

This was classified as a HS-AO-5 avalanche. The falling cornices released an initial slab high on the Baldy chute and this in turn released several sympathetic slabs in adjacent chutes. The initial slab was about 4 feet deep, and it is hypothesized that it released on the sliding surface formed during the previous cornice blasting (HS-AE-3 on March 22, 1967). The sympathetic slabs varied in thickness from 1 to 4 feet. The debris, which varied in depth up to 12 feet, was scattered over the Ballroom and the upper Main Street areas. The slide ran about 1500 feet.

Comments

How was it possible for Perla to have survived this major slide? Some speculations are: first, that Berry held the belay just long enough to restrain Perla above the main debris; and second, Perla was thrown into an eddy that avoided blocks and carried him to a shallow deposition area. Finally, he was able to fall back on his avalanche training and do essential things at the right moments. Luck was with him also in allowing his outstretched arm to break through to the surface when the slide stopped.

Perla had with him an additional safety device—the broken belay rope—that should have led rescuers to him had he not been able to get a glove above the snow. The rope was at least 50 feet long and should have served as an avalanche cord; however, the entire length of rope was buried beneath debris. In this case, both Perla and the rope had nearly come to rest on top of the snow when snow from above buried him and the rope. This is one example of how an avalanche cord can be buried along with its user and is enough to cast doubts on the reliability of avalanche cords.

Several classical mountaineering errors were made:

1. The group set out to accomplish an extensive mountaineering project despite an unfavorable weather forecast. (Ironically, the group was cognizant of the weather forecast and had expressed reluctance to go on this mission.)
2. The group was not equipped for bad weather.
3. The group used an undersized rope. A 7/16-inch (11-mm) rope should have been used.
4. Two people were belayed on the same rope.
5. Two people were on the same cornice at the same time.
6. The belayer was not experienced and did not assume a stable position.
7. The drillers straddled the drill hole line instead of standing behind it.

The blasting party failed to evaluate the instability of the cornice. They were misled by the stability of the cornices when first blasted in March. The March cornices were mostly vertical or only slightly overhung. The April 21 cornices had a more pronounced overhang, possibly due to a plasticity caused by the intense solar radiation during April.

Another important contribution to this accident is the fact that a cornice that has reformed after the primary winter cornice has been removed is much less stable than the first one. A mature cornice is held onto the mountain by tensile strength of the continuous layers of snow running back into the cornice. In a re-formed cornice, these layers are not continuous. A dangerous discontinuity exists where the new cornice formed on the fracture line of the old, a discontinuity that lies precisely at the zone of maximum stress.

Another contribution which added to the group's misplaced confidence was the early morning pack howitzer firing below the cornice area which released nothing. It is interesting that the falling cornice accomplished what the pack howitzer could not—the release of a size 5 avalanche.

Cornice blasting is, by its nature, a dangerous task: working too far back from the edge can be ineffectual. Blasting crews must always be aware of their vulnerable position on the cornice. It is recommended that an observer be stationed at a location from which he can observe the undercut of the cornice. He can then call positioning instructions to the workers on the cornice. In addition, whenever possible the cornice worker or the belayer should be tied into a fixed anchor—rock, tree, lift tower, etc. In many cases, a standard belay cannot hold against the force of falling cornice blocks and avalanche snow.

Finally, two policy changes at Alta were made because of this accident. First, a great gap in the training of new avalanche men was revealed. A more thorough training program was initiated to increase the skills of the avalanche workers. Second, the Ballroom is no longer left open to skiers while blasters are working on the Baldy cornice above. Of all the mistakes made, this was the worst.

1 caught, buried, and killed

Weather Conditions

Through November 25, 39 inches of new snow had been recorded for the month at the weather site on the east side of Loveland Pass, 4 miles from the Arapahoe Basin Ski Area. Twenty-five inches of the total had fallen in the last 5 days with a water equivalent of 1.61 inches. the winds during this 5-day storm period were westerly and averaged 18 m.p.h., but gusted to over 50 m.p.h.

Sunday, November 26, broke clear, cold, and windy. Before sunrise the temperature was -2°F. A maximum of 14°F was recorded at 1400 with a rapid fall in temperature after that time. Winds were strong and gusty all day, blowing from the WSW, averaging 16 m.p.h., and again gusting to about 50 m.p.h.

Accident Summary

Earl Gentry, 39, was a National Ski Patrol member who had been patrol leader at Arapahoe Basin during the 1966-67 season. He had earned an avalanche patch from the National Ski Patrol system and was considered a competent skier and patrolman. On Sunday, November 26, Gentry signed on for duty at Arapahoe Basin as a volunteer patrolman. He was assigned two one-half hour duty stations, one in the morning and one in the afternoon.

On the morning of the 26th the ski patrol thoroughly checked out the area with skis. No explosives were used. Conditions were found to be extremely wind-blown, with heavy deposition on the lee sides of ridges and very wind-crusted conditions. No avalanche activity was noticed, nor did the ski patrol get any kind of activity from their skiing. The area was opened for business and was lightly skied during the day. After the lifts had closed, Gentry began his "sweep" with the other patrolmen.

Gentry and five other ski patrolmen were sweeping Lenawee Mountain in pairs of two; his partner was Gail Kersion. They separated from the rest of the group on the upper part of the mountain. They were assigned the Lenawee Glades. At the top of the Lenawee lift, Gentry saw tracks going into one of the glade areas. They decided to separate, with Kersion going down the west gully, and Gentry checking out the ski tracks more closely. They agreed to meet at the upper meadow. The time was about 1615.

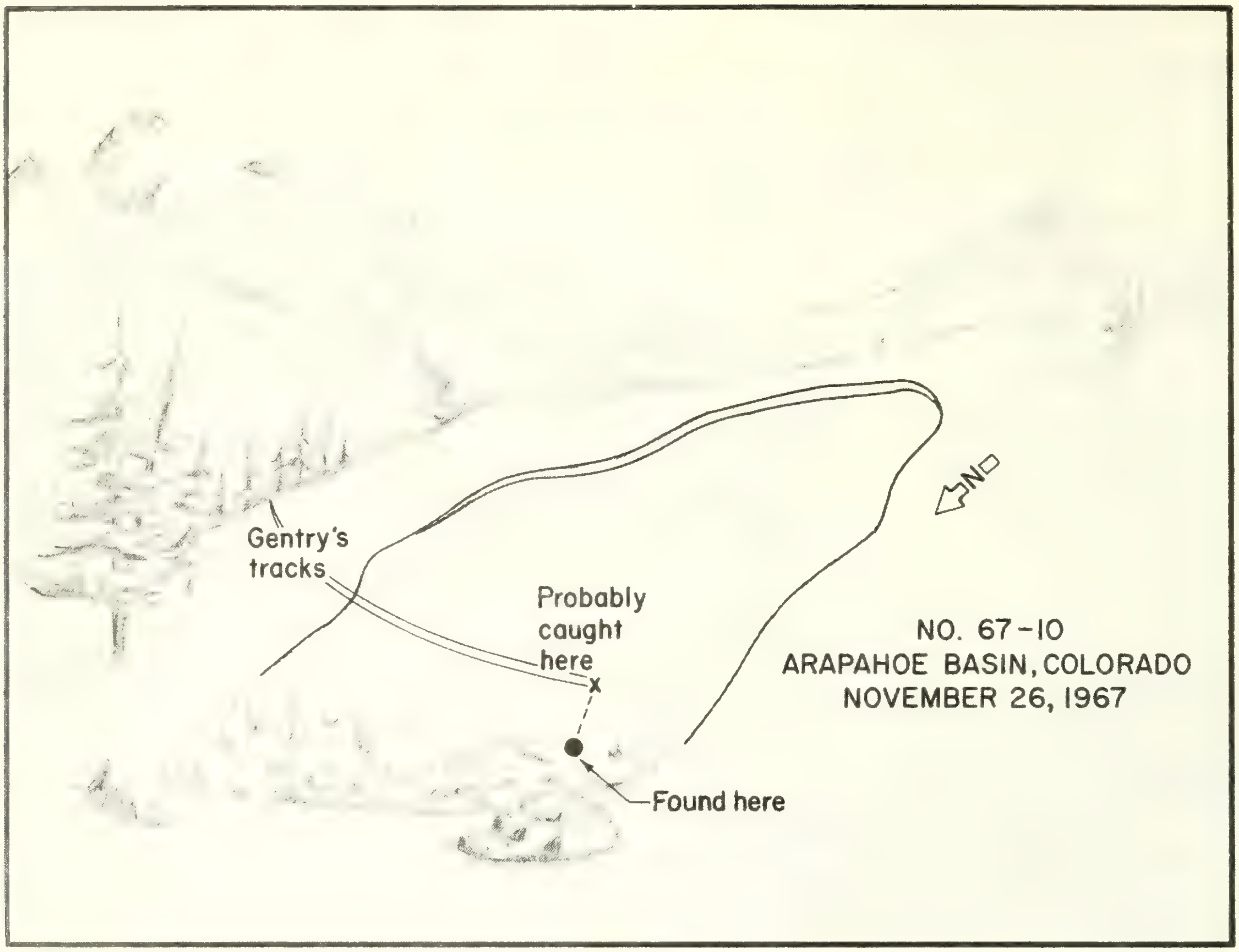
Kersion got down to the upper meadow in approximately 5 to 10 minutes and waited for Gentry. When he did not come, she called several times and got no answer. She then walked up toward Midway and looked up the area where Gentry should have been. She saw no one. She called again, but got no response. This took approximately 10 minutes. The light was beginning to fade, and she decided she had better get down. She thought possibly Gentry had gone on down before her. She arrived at the patrol room in approximately 10 more minutes, and found that Gentry had not arrived there either.

Rescue

The "super-sweep" patrol was alerted at the top of the mountain. The super-sweep is a back-up system where two patrolmen are left at the top of the mountain until all patrolmen report in at the bottom. Their purpose is to assist patrolmen who get in trouble, and also bring a toboggan if any patrolman finds an accident during the sweep.

The super-sweep team of this day was Will Green and Margie Lincoln. They proceeded to the Lenawee area after the phone call indicating Gentry's disappearance. Green was the first person to reach the area of the accident. He found that skiing in the Lenawee area was difficult and dangerous due to drifts and wind crust. Near the head of the west gully they found a set of tracks, which they took to be Gentry's. These tracks were following the route that is taken by most skiers who want to return to the Drummond Lift from the Lenawee area. The tracks were partially obscured by blowing snow and were the only tracks noticeable in the area. They stopped and called twice, but got no reply. The set of tracks ended at the edge of a fresh avalanche.

Toward the lower part of the avalanche,



they could see the front half of a ski sticking out of the snow. When they reached the ski they could see a rust-colored parka through cracks in the snow blocks, and surmised that it was Gentry. They quickly uncovered his head and chest. Green started mouth-to-mouth resuscitation, while Lincoln went for help.

The victim was found on his side and partially on his back under about 1½ feet of snow, facing sideways. His left ski boot was almost out of the snow, and part of his left ski was sticking out of the snow. He was wearing a crash helmet or racer's helmet, which was still on his head. His mouth and nose had no snow in them and his air passages were clear. He had no ice mask. There was discoloration of the snow near his nose and mouth; it is not known whether this was blood, or what caused the discoloration. The snow in the slide was loose enough so that it could easily be scooped away with the hands.

At approximately this same time, four patrolmen started up the chairlift with oxygen. When these patrolmen arrived at the scene, artificial respiration was still being administered. The victim was still partially buried at that point, and the patrolmen completed unburying him. Shortly thereafter, the first doctor arrived. At the time the doctor arrived, mouth-to-mouth resuscitation and closed-chest cardiac massage was being performed. At approximately 1800, the victim was declared dead.

Avalanche Data

This fatal slide was classified as HS-AS-1. The slide ran about 150 feet down a 31° slope (37° in the starting zone). The slide was only about 25 feet wide at the starting zone and about 90 feet at its widest. The fracture line was about 22 inches at its deepest point, and the debris consisted of angular snow blocks of various sizes.

Extremely hard-packed, wind-crusted snow conditions existed; some deposition areas were so hard that the handle end of a ski pole could not be thrust through the surface. Many deposition areas sounded hollow (like a bass drum) under ski. Some of the deposition areas had fractured on their own accord but had not slid. It looked as if these had fractured the evening before or during the night. The first rescuer along the road above the avalanche site got a small fracture from his skis as he neared the avalanche site.

Examination of the snowpack in the fracture zone revealed the following conditions: The depth of snow on the ground was shallow—slightly more than 20 inches—and in places the avalanche dug to the ground. The fracture line itself was approximately 16 inches deep. Just above the ground lay 5 inches of well-developed depth hoar. The depth-hoar crystals were particularly large and could actually be photographed without the aid of a special lens for the camera. Above the depth hoar was a thick layer of fine-grained old snow (equitemperature-metamorphism crystals). A hard, dense wind crust formed the surface of the snowpack.

Comments

The snow that fell early in November, because of its very shallow depth, developed into depth hoar. On the 20th of November, snow began falling again, accompanied by strong winds, and this developed a hard-slab situation. The patrol skied over this slab the morning of the 26th and got no activity, and the light skiing during the day resulted in no activity. The slab was so hard that skis would barely penetrate it.

The area of the avalanche is a north-facing slope and receives very little sunlight during the day. A sharp temperature decrease occurred during the 2 hours immediately preceding the slide. From 1400 to 1600, the temperature fell from about 14° to 4°F. This temperature decrease may have increased the tension of the slab, thereby increasing its instability. This may explain why the slope avalanched under Gentry's weight while not releasing when skied earlier in the day.

There is a debate among researchers and field personnel over the mechanism labeled "temperature release." Presently there are no data to indicate the magnitude of the expansion or contraction created within the snowpack by temperature changes. Some researchers believe that great instability can be induced by temperature changes but others believe the effect is negligible. In any event, it should be noted that temperature-gradient crystals (in this case, depth hoar) have been found in almost all reported cases of "temperature release."

A further note should be added: test skiing is often ineffective under hard-slab conditions. Explosives give a more reliable test of hard-slab instability. The hollow sound beneath the snow and the appearance of cracks in the snow should have alerted the patrol of the hazard in the area in spite of the test-skiing results.

It appears that Gentry was probably caught by surprise. The fracture line was about 75 feet above the point where he entered the slope. Brittle failure probably occurred with the whole area fracturing at once into large blocks. The slide pushed him over (head downhill) and slid over him. He could not have been carried more than 10 or 15 feet. The weight of 1 to 1½ feet of snow was sufficient to hold him down.

1 caught and partly buried

Weather Conditions

Snowfall this winter had been much below normal in the Cascades. On January 27, snow depth was 45 inches at Alpental; twice this amount would be present in a normal winter. On the 26th, 8 to 12 inches of snow had fallen on the upper mountain with the temperature holding near 25°F. Winds of 10 to 15 m.p.h. had blown without transporting much snow. The 27th dawned clear and much colder.

Accident Summary

Early Saturday morning, January 27, four patrolmen set out on their control route. All but Terry Holdy were experienced in avalanche work. The crew was skiing into Edelweiss Bowl from the top of Chair No. 2 with the objective of test skiing or hand charging several small chutes which were uncontrollable from the avalauncher position.

At 0730, they reached a small 35° chute in the bowl. One patrolman threw a hand charge up into the chute and then all except Holdy retreated to cover in nearby timber. Holdy took cover behind a tree but not nearly as far away as the other three men.

The explosion set the chute in motion and also released a sympathetic slide in the trees. The snow fractured 50 feet above Holdy and swept him away from where he was standing. He was carried 50 feet downhill and buried waist deep. Immediately his three companions skied downhill and helped dig him out; he was uninjured.

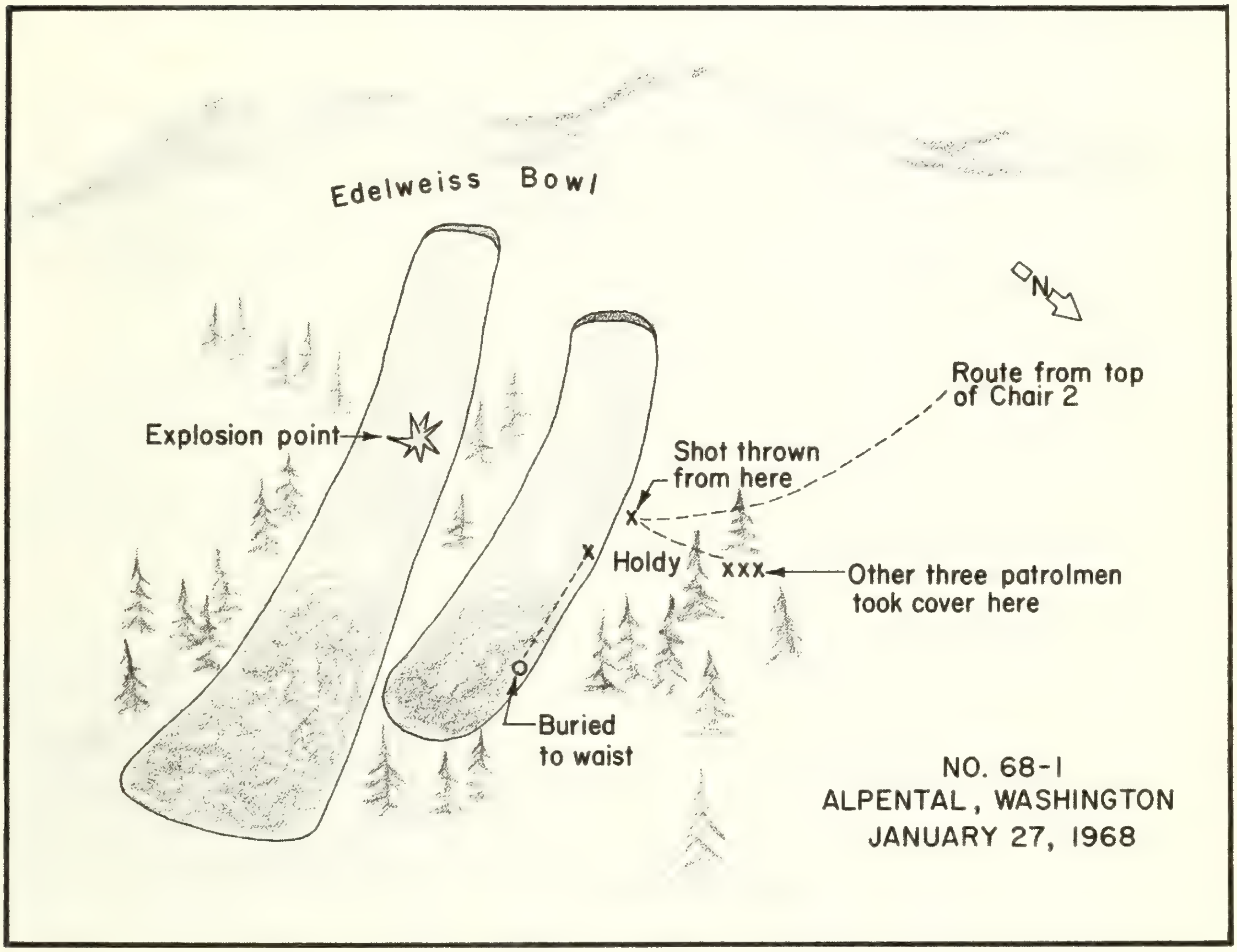
Avalanche Data

The slide was a small, sympathetically released slab. The fracture line was 1 foot deep and 50 feet long. The slide moved about 150 feet down the slope.

Comments

Holdy's lack of experience led to trouble in this incident. The other three patrolmen had retreated far enough away so that the sympathetic slide did not affect them. Holdy also felt that even though he was not as far away, the timber on this slope would keep it from sliding. This confidence was unfounded; the timber was not nearly dense enough.

After this incident, the Edelweiss Bowl was no longer controlled from below by hand charging. This kept the bowl closed for a large part of the winter. A recoilless rifle has since been installed to control this area.


Edelweiss Bowl
N
Route from top of Chair 2
Explosion point
Shot thrown from here
Holdy
Other three patrolmen took cover here
Buried to waist
NO. 68-1
ALPENTAL, WASHINGTON
JANUARY 27, 1968

2 caught, 1 partly buried

Weather Conditions

A major storm moved inland on January 30 bringing moderate but continuous snowfall to the Cascades. During the 5-day period from January 30 to February 3, 36 inches of new snow containing 4.00 inches water equivalent fell at Stevens Pass; this increased the snow depth from 39 to 57 inches. In addition more than an inch of rain fell on February 2 and 3, adding to the hazard. Moderate westerly winds caused light drifting.

Accident Summary

At 0800 on February 3, Snow Ranger Bob Lawrence, Assistant Snow Ranger Gert Gruenwoldt, and pro patrolman Merle Bergren skied away from the top of Chair No. 1 to do the last remaining avalanche control work of the morning. They entered a slope called the Headwall, a northeast-facing bowl that had loaded up heavily with wind-transported snow. Bergren threw a one-pound block of HDP onto the slope. The charge hit the windpacked slope, did not penetrate, and rolled on down the slope to explode ineffectively. Because this was the last charge the group had with them, they decided to "ski off" the slope.

Bergren went first, followed by Gruenwoldt and Lawrence. As Bergren worked his way down and across, the snow suddenly fractured 20 feet above him. The moving snow knocked him off his feet and swept him to the bottom of the slope, a distance of 200 feet. He was buried to the waist and was able to free himself.

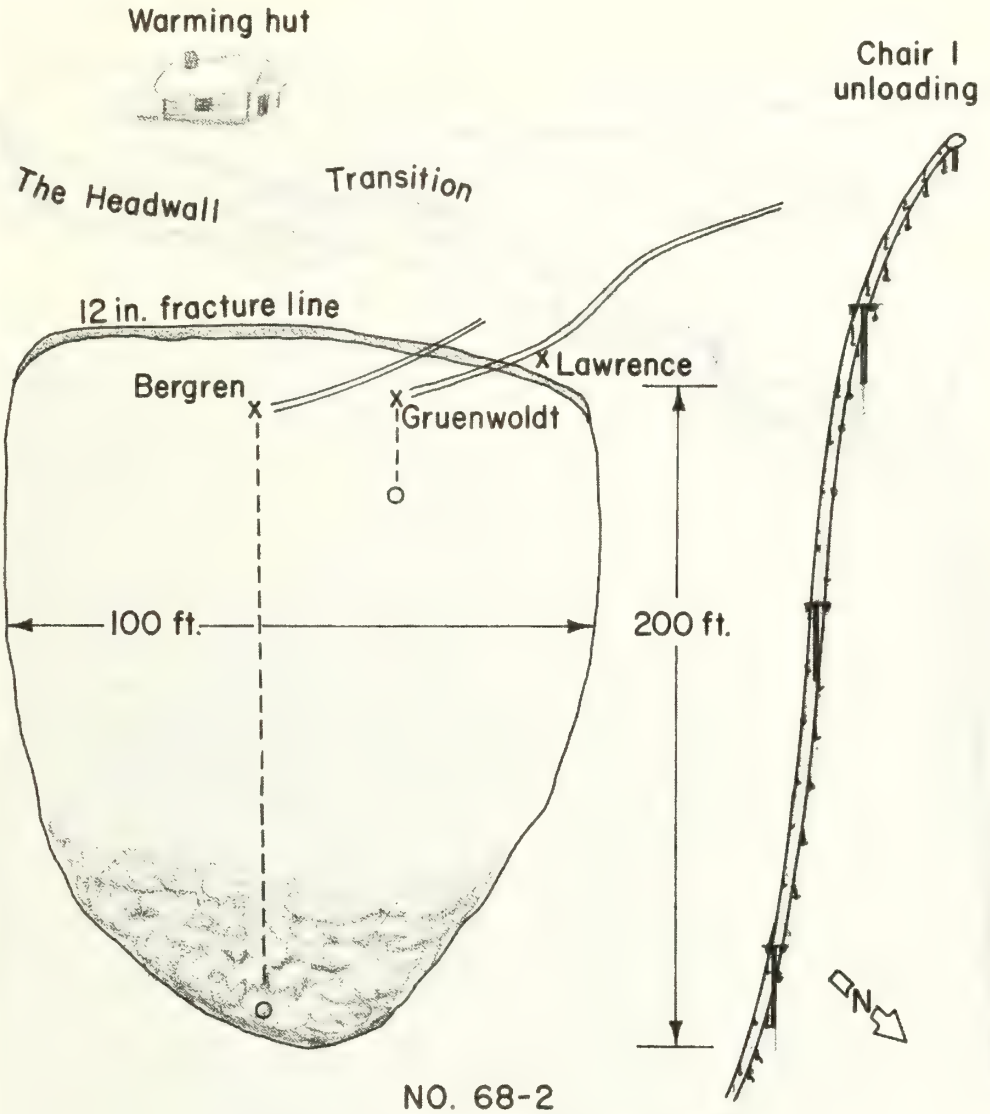
Gruenwoldt was behind Bergren and slightly lower on the slope when it fractured. He was carried approximately 10 feet before he was able to arrest himself with a ski pole. Lawrence, last in line, was standing on the fracture line and was able to step back out of the moving snow.

Avalanche Data

This slide was a SS-AS-3. The 12-inch fracture line extended across most of the width of the slope for a length of 100 feet. The slide carried 200 feet downhill and piled debris several feet deep in the runout zone. This path is an active one, running several times each winter.

Comments

The Headwall is too big a slide path to be ski checked safely. The control team knew this, but when they ran out of charges they decided to ski it anyway. In the interest of safety at the expense of time, they should have skied down and returned to the slope with some extra HDP blocks. A shot cord attached to the charge is effective to hold the charge on the slope when the snow is hard.



NO. 68-2
STEVENS PASS, WASHINGTON
FEBRUARY 3, 1968

1 caught and buried

Weather Conditions

Ten inches of new snow fell at Alpental on February 1 to 3. This was followed by 2.75 inches of rain on the 4th during which time 24 natural wet slides, all medium to large, ran in the ski area.

Four days of clear, sunny, and mild weather followed. Moderate west to northwest winds had blown during this period. The morning of February 8 broke clear with a temperature of 22°F. Snow depth was 59 inches, a settlement of 7 inches over the last 6 days.

Accident Summary

At 0800 on the 8th, three pro patrolmen departed Chair No. 2 to check out Edelweiss Bowl and the adjacent ridge runs. Terry Holdy (see No. 68-1) was one of the group and still was considered inexperienced in avalanche control work.

The party was test skiing and hand charging many small chutes and gullies and had not had any significant results. They reached a small chute beneath Chair No. 2 and decided to test ski it. Pat Bauman entered high in the chute, and at the same time, Holdy entered below him. Bauman released a small slide which caught Holdy below and knocked him off his skis. The fast moving snow engulfed Holdy and carried him 100 feet down the chute. He was buried horizontally under about 1 foot of snow.

Bauman and the other patrolmen immediately skied down the chute and dug Holdy out. He was badly shaken up but unhurt. He had lost one ski pole in the slide.

Avalanche Data

This slide was a L-AS-1 that slid a little more than 100 feet. The gully was only 30 feet wide. Snow sliding in this gully funnels down and piles debris deep enough to bury a man easily.

Comments

The error here was made in not informing a new man on the proper procedure of test skiing. He should have never entered the narrow chute while another skier was in it. The gully was especially dangerous because even a shallow slide would make a deep deposit below. It should not have been test skied without a belay.

This was the second time in 11 days that the victim had been buried in a slide (see No. 68-1). Both accidents resulted from his inexperience and from lack of proper guidance from the team leader.

1 caught and buried

Weather Conditions

Weather records from Aspen Mountain showed that slightly below normal snowfall had fallen this winter through the middle of February. On February 12 and 13, 9 inches of snow fell and 4 more fell on the 15th, bringing the snow depth to 46 inches. The temperature ranged from 16° to 24°F on the 15th, and light and variable winds were blowing. The winds had been westerly and considerably stronger the previous two days.

Accident Summary

On the morning of February 15, Bill Flanagan, a ski patrolman and lift operator, at Aspen Highlands, and Matt Wells, a ski patrolman, left Loge Peak at the top of Aspen Highlands Ski Area. They were headed for Highland Bowl to check on snow conditions and to ski the powder if conditions were stable.

Highland Bowl is an enormous, open bowl on the east flank of 12,381-foot Highlands Peak. The bowl is several thousand feet across at the top and descends nearly 4000 feet vertically to Castle Creek. The top of the bowl has no trees and a slope of about 35°. There is evidence that huge avalanches in the past have run the entire distance to Castle Creek. The bowl is beyond the ski area boundary and is not frequently skied. Flanagan gives a chilling personal account of what happened on this particular morning.

"Matt and I started down along the right (south) shoulder of Highlands Peak at approximately 1100 the morning of February 15. The virgin powder was very dry and light but so deep that we found we were unable to ski fast enough to make turns. That right shoulder simply didn't have enough pitch. So we swung out into the open bowl, staying just to the left of the first finger of growth running up the face.

"We stopped at the top of the very face of the bowl and threw a 7-stick, 40% charge down into the path we intended to take. The detonation had no effect, however. An earlier charge of the same size which we had pitched into the face from the top of the peak had released nothing either. Having witnessed this, we were confident the snow would hold up so we started making turns down a pitch which I would estimate at 35°.

"I made perhaps three or four turns before stopping to photograph Matt as he came down. He stopped just below me and we agreed that I'd ski a bit farther down and shoot up my film as he came down to me.

"I had made perhaps three turns when I leaned uphill too much and fell back into the snow. I started to sit up and had looked up at Matt, who was perhaps 30 to 40 yards above me, when it broke.

"Matt recalls that it fractured just below him. I can recall that the snow seemed to suddenly settle and I noticed several 'whirlpool' effects in the snow surface around and above me.

"I was rolled under almost immediately, and breathing hard as a result of the deep powder skiing, my mouth immediately filled with snow as I attempted to breathe. Try as I did, it was absolutely impossible to expel the snow from my mouth. The ball of snow simply packed harder each time I tried to gulp air around it.

"I recall I was able to swim and did so as naturally as one would were he trying to surface in a pool of water. I recall only a 'whooshing' sound of sorts and it gained speed incredibly fast. It seemed I knew where the top was because it seemed there was always a lighter side. I had started out with my pole straps over my wrists but can't recall when I lost my poles.

"Suddenly the pressure increased tremendously. I recall having the thought, 'Not me, not this way, not like this.' But it squeezed so terribly that I was unable to move arms or legs and I must admit that at this point I literally gave up. The pressure was so great it just forced that thought into my mind. (For some time after, recalling that thought would sit me bolt upright in bed at night.)

"A terrific drag suddenly built up on my right leg and was just as suddenly relieved when the ski tore off. I remember realizing this even as it happened, and I know that this is the important reason for my surviving this horror. Once free of that ski I started rolling again, and almost immediately the terrific pressure began to ease and I was again able to swim, or at least move my arms.

"I remember that it slowed down and then stopped very quickly. I felt it lighter above my shoulders and struggled my arms loose and broke through to daylight.

"The ball in my mouth was so big and hard I was unable to get it out from behind my teeth. I was able to crush it bit by bit with my front teeth and finally reduced it to a size I could at last spit out. I then dug my legs free, released the left ski and stood up.

"I realized immediately why the pressure had increased so suddenly when I looked back up the slide path. I could see only about 100 yards of the deposition. From there it climbed abruptly to the left up the sidewall of the bowl. I knew that it piled up on itself as it dove into the floor of the bowl, and I must have been quite deep at that particular moment.

"I would estimate the length of the slide at somewhere between 400 and 450 yards. I shouldn't think that it ran for much more than 10 seconds as I'm quite sure that had it been much longer than that (15 seconds at best), I certainly would have passed out for lack of air. As I said, I was breathing heavily even as it broke. My throat was so sore that taking a breath actually burned, and for a good half hour I couldn't draw a full breath.

"I figured that I was still in plenty of trouble. I had no poles and only one ski with several miles of chest deep, untracked snow to negotiate down to the Castle Creek Road, but then I spotted Matt high up on the rim of the bowl. Until then I wasn't completely sure that he hadn't been caught and carried down too.

"I was standing at the bottom of an enormous bowl whose walls were nothing but uninterrupted open snow just needing the slightest trigger to bring them down. I was reluctant to move off the slide path knowing that I would just flounder in the unpacked snow. Matt spotted me and, in spite of the danger, managed to get down to me. Thinking it over later, I realized that was the bravest thing I had ever seen done. Matt and I are the fastest friends since that day.

"He gave me his poles, and after many hours of agonizing effort we made it down and out to the road."

Avalanche Data

This avalanche was a SS-AS-3. It slid on the north-facing wall of Highland Bowl for a vertical fall of about 800 feet. If Flanagan's estimates of the length (400 to 450 yards) and duration (10 to 15 seconds) of the slide are close, the avalanche traveled between 55 and 90 m.p.h.

Comments

Flanagan offers these comments: "This was one of those rare cases where a fool makes every foolish mistake in the books but somehow lucks out. One look at that pitch should have told me that under the conditions, as steep as it was, it would never hold up. The wind and drift factor that bowl gets make it absolutely unskiable almost anytime. I'm wiser now but far more importantly, I'm still terrified. My fear alone should keep it from happening again."

Flanagan was indeed fortunate to break through to the surface just as the slide was stopping. Had he been completely buried, he probably could not have moved enough to dig himself out. With his mouth full of snow, he would have certainly died of suffocation before being rescued.

Many victims killed in avalanches are found with their mouths full of snow. Flanagan's experience shows how easily avalanche snow is inhaled. An avalanche victim's chance of survival is increased if he can keep his mouth closed while in the snow.

In this instance, when the snow tore off Flanagan's right ski, his chances of survival were increased. Being less restricted, he was able to make a thrust toward the surface when the snow slowed down. With the ski on, he may have been held beneath the surface. In other accidents, skis remaining attached to a buried victim have protruded above the snow surface allowing rescuers to locate the victim quickly.

2 caught; 1 partly buried and 1 buried; 1 killed

Weather Conditions

Weather records at Alta, Utah indicate that the winter of 1967-68 began with extremely light snowfall in November, followed by above-normal December snows. January 1968 followed with less than half its normal snowfall.

Snow began falling in the Wasatch on February 12 and continued on and off for the next 14 days. By the 20th, more than 40 inches of snow had fallen bringing the depth of snow on the ground to near normal. A warming trend late on the 19th brought rain to the western slope of the Wasatch at elevations below 7500 feet. In Rock Canyon, just east of Provo and about 20 air miles south of Alta, rain was falling on top of several inches of new snow on the evening of the 19th.

Accident Summary

On Monday night, February 19, the members of Boy Scout Troop 40 in Provo, Utah had their weekly meeting. After the meeting, three scouts—Robert Breckenridge, 12; Brian Tolman, 13; and Gordon Duke, 13—and assistant scoutmaster Don Hamilton, 29, decided to take a short hike up Rock Canyon on the east edge of Provo. Edison Breckenridge, Scoutmaster and father of Robert, drove the group to the mouth of the canyon and said he would wait until the hikers returned. Tolman gave the following account of the accident. The time was about 2030.

"We went up the mountain and hiked about three-quarters of a mile up the canyon. Then we sat down and rested. We were talking and throwing snowballs across the creek.

"I heard this rumble. It was a big noise —pretty loud. I looked back of us and saw this big mass of snow coming. It was bumping and flying over the rocks higher above us.

"Gordon and I jumped up and just began running down the trail. We ran as fast as we could for about 100 yards. During this time, I didn't see Robert or Don.

"We stopped and yelled back. We heard Don yell back. He said he was trapped in the snow. We waited for a minute. It seemed like there was still snow coming down. Then we went back.

"Don sent Gordon down the canyon for help. Don couldn't move, so I broke off a big stick and began digging to get him out. It took about an hour to dig away the snow so Don could get out of the hole. I just never did see Robert again."

Hamilton related his experience: "I first heard a noise like a jet aircraft overhead but saw nothing. The next thing I felt was the snow engulfing me. I swam like crazy just trying to keep my arms and legs from being trapped. I saw Robert slightly to my left as the snow hit but never saw him after that."

In all, two of the scouts escaped the avalanche completely, Hamilton had been buried to the chest, and no sign at all could be found of Robert Breckenridge.

Rescue

Gordon Duke came running out of the canyon and told Edison Breckenridge, who was waiting in the car, what had happened. They raced down to Provo and notified the Utah County Sheriff's Office. They hurried back to the scout meeting headquarters and organized some Explorer Scouts into a rescue party. Meanwhile at the accident site, Hamilton and Tolman had found no sign of Breckenridge. The debris appeared to be 15 feet deep in places.

The sheriff notified the Utah County Jeep Patrol, the Timp Haven Ski Patrol, the Alpine Rescue Club from Brigham Young University, and the Alta Ski Patrol. Flashlights, gasoline lanterns, probe poles, and shovels were carried up Rock Canyon to the accident scene. A Caterpillar tractor was also sent up the canyon to push away some of the debris. A snow cat also was pressed into operation ferrying men and equipment up the canyon.

Several probe lines were set up. At 0230 on Tuesday morning, February 20, the body of Robert Breckenridge was found by the probers. He was found under 10 feet of snow and had died of suffocation. He had been buried 6 hours. About 150 volunteers had participated in the futile rescue.

Avalanche Data

This was a natural avalanche that had released well above the group. Most likely, it was a wet slide resulting from the rain falling on the recently deposited snow. The slide came off some high cliffs and fell into the narrow canyon where the party had stopped. It was about 100 yards long and about 50 yards wide. Some boulders and trees were carried down by the avalanche.

Comments

This tragedy resulted from the scouts being simply "in the wrong place at the wrong time." This being such a short hike, the group had not even thought of avalanches. The hazard of their resting place—at the foot of a row of cliffs heavily laden with snow—was concealed in darkness. Hiking or touring groups should never knowingly pause beneath apparent avalanche paths but should move rapidly across the runout zone.

The effectiveness of swimming is demonstrated by this accident. Scoutmaster Hamilton swam vigorously with the snow; this gave him some maneuverability and apparently saved his life.

During the rescue, many of the rescuers were fearful of more avalanches falling from adjacent cliffs. This case offers an example of a nighttime rescue mission being carried out during high avalanche hazard. It is a hard and critical decision that the rescue leader must make: the safety of many rescuers must be carefully weighed against the chance of recovering the avalanche victim alive.

1 caught and partly buried; 1 chairlift damaged

Weather Conditions

Warm weather preceded a storm which began on February 19 in the Bridger Range of Montana. On February 18 and 19, temperatures were generally above freezing, with some rain occurring on the 19th. Snow pits indicated that south slopes had become isothermal, and the presence of ice crystals in the pack on February 21 indicated that there had been free water present. No wet slides had occurred however. North-facing slopes were not quite isothermal. Only a little depth hoar was observed.

A warm Pacific storm moved in on February 19 with rain that turned to graupel and then continued as mixed graupel and rimed snow. The snow line and freeze elevation during the storm was at the base of the Bridger Bowl Ski Area or somewhat below. The warm temperatures caused the new snow density to be high, estimated at 15 to 22 percent. Snowfall during this storm was 14 inches on February 20, 2 inches on the 21st, and 10 inches on the 22nd.

The average windspeed exceeded 15 m.p.h. for the period between noon on February 19 and 2000 on February 20; peak gusts were well over 50 m.p.h. Perhaps because of the high-density snow that was falling, there was little evidence of wind-transported snow below the highest ridge. Wind direction was south to southwest, and four northeast-facing slopes slid naturally during the night of the 19th.

Snow pits dug on the 21st revealed at a depth of 16 inches a graupel layer resting on a hard, stable layer below. It was felt there was some bonding between the new snow and old surface. Test skiing did not release any slides; however, cracks were observed running ahead of skis, an indication of slab conditions. No explosives were used.

Snow continued to fall on the 22nd; this snow also was graupel and heavily rimed crystals. No sluffing had occurred, and the possibility of widespread slab conditions was recognized even though there was little evidence of wind-transported snow.

Accident Summary

On Thursday morning, February 22, Snow Ranger Don Michel and District Ranger John Butt arrived at Bridger Bowl for control operations at 0800. It was not until about 0845 that the lift operator arrived at midway to start Chairlift No. 2 (now called the Alpine Lift), and the avalanche control crew went up the hill. Due to the new snowfall and the indications of instability observed in snow pits the previous day, both upper hills were closed. To save time, the group crossed Bridger Gully to the North Bowl gun and arrived at about 0915. Clouds restricted visibility to an area 500 feet below the ridge. Six rounds were fired with the following results.

As a warning to alert the lift operators, the first round was fired into the middle of Bridger Gully, about halfway to the top. No release or movement of snow was observed. The second round was fired at the southeast-facing slope of Bridger Gully. This released a large slab (SS-AA-5). A secondary fracture line ran south across the lower cliffs of Bridger Gully to the edge of the North Bowl under the power line, releasing the area that the crew had just traversed. Another fracture ran south across the two-thirds point of Bridger Gully. A third secondary fracture continued around the ridge to the north above Chairlift No. 2 motor room and 100 yards into the Northwest Basin. Butt saw a dust cloud near the lift shack and was concerned. They looked through the gun sight and could see the operator shack was not damaged. Trees restricted their view of the motor room, however, and it could not be determined if there was any problem.

The third shot from the 75-mm rifle was placed on the northeast-facing slope of Bridger Gully, about two-thirds of the way to the top and 100 yards above the last fracture line. This released another slab in Bridger Gully, as expected; however, a secondary fracture first ran a quarter mile across the lower cliff of the North Bowl. Then another fracture line ran across the North Bowl at the ridge line, releasing two-thirds of the entire

North Bowl. A loud roar accompanied this avalanche (SS-AA-5).

The fourth shot from the 75-mm rifle was placed about 200 feet down from the top near the southwest corner of the North Bowl. This released about one-fifth of the North Bowl in that area (SS-AA-3), but it did not release the area below the "catwalk." The "catwalk" was not shot with the rifle because it is too close to Chairlift No. 1 (now called the Bridger Lift).

The clouds lifted briefly, and another shot was placed about 100 yards below the ridge in Bridger Gully. This released another slab from the upper slope (SS-AA-3).

The sixth shot was placed high on the ridge between Bridger Gully and the North Bowl above the fracture lines. Another slab was released which descended into both the North Bowl and Bridger Gully (SS-AA-3). The firing was finished at about 1030.

By this time the gun crew was aware that Chair No. 2 had not yet begun running and felt that something must be wrong. While they were cleaning the gun, a patrolman skied over with the news that the top terminal of Chair No. 2 had been hit by a large avalanche. He said that apparently no one was injured but the motor room had been destroyed. Michel and Butt then skied over to Chair No. 2 to survey the damage.

The top terminal had been hit hard by the avalanche coming off the ridge above. The slide had destroyed the motor room and had damaged the bullwheel and the unloading ramp. In addition, one of the lift operators, George Platt, had been buried to his chest. Platt and Wes Hayes, who was the other operator and who had escaped the slide, gave the following account of the accident.

Platt and Hayes were at the top of Chair No. 2 checking out the lift and preparing for the day's operation. Platt had been informed by Butt and Michel that the upper portion of the lift was to remain closed until the snow rangers notified them it was open. They told Platt they would be firing the North Bowl gun and the first round would be fired high so they would have time to get into the motor room for the rest of the firing.

The first round was fired at about 0930, and no slide resulted. Platt and Hayes then left the motor room and were walking toward the lift operator's shack and unloading platform about 50 feet away. At this instant, the second round was fired into Bridger Gully where it released a large avalanche and also caused a secondary release on the ridge directly above the motor room. Hayes saw the avalanche coming and yelled. He ran ahead of the lift operator's shack and was safe. Platt turned and ran back for the motor room. As he reached the door, the avalanche hit the building, carrying the wooden walls and roof over his head. He said some of the avalanche also passed over him, and he was buried up to his chest in snow. He quickly dug himself out and was not injured. They then phoned the base of the hill and described what had happened.

Avalanche Data

The avalanche that struck the lift terminal was the north flank of a SS-AA-5 avalanche in Bridger Gully. The 2-foot fracture line originated in the gully and came around the ridge above the lift. The main part of the avalanche dropped 1000 feet vertically down Bridger Gully. A total of 13 avalanches were released on the 22nd, all soft slabs of medium-to-large size.

This was a major avalanche cycle at Bridger Bowl during which all slopes avalanched regardless of aspect. This was not slab resulting from wind but rather a uniform slab forming from the graupel and heavily rimed crystals.

Comments

This incident is a good example of critically unstable soft-slab conditions that formed without wind deposition. The new snow that was falling was high density and was in the form of graupel and heavily rimed crystals which formed widespread soft slab. In this case, all slope aspects were equally unstable.

The graupel layer found in the snow pit on the 21st provided an ideal running surface for the slab. Graupel seldom bonds to an old snow surface but rather remains in the pack as a layer of loose pellets resembling BB's. The combination of soft slab and a graupel layer should have been a "red flag" warning the avalanche team to initiate control before conditions worsened.

The ski area was not controlled by artillery on February 20 and 21 because these were the snow ranger's days off and there were no other Forest Service personnel available to perform his duties. To compound the problem, blind firing was not performed at Bridger Bowl at that time. Consequently, even if the snow ranger had been available, the bad weather would have restricted visibility and severely limited any artillery control. Both these weak points in the avalanche safety plan have been remedied: backup Forest Service personnel are now available and blind firing is now standard practice at Bridger Bowl.

The chairlift that was damaged had been newly installed for the 1967-68 season. Clearly, the location of the top terminal is not safe. More consideration should have been given to avalanche potential before the chair was built. A splitting wedge or some other type defense structure should be built to protect this lift terminal. Since this accident, further damage to this lift has been prevented by a more complete program of avalanche control.

No. 68-7 Leadville, Colorado February 24, 1968

1 caught, buried, and killed

Weather Conditions

The latter half of February 1968 was generally snowy over the central Colorado Rockies. Snows fell daily at most weather reporting sites in Colorado during this period. On the morning of February 24 alone, 10 inches of new snow were recorded at Leadville; also, moderate-to-strong northwest winds were blowing, creating extreme avalanche conditions in the Leadville area. Numerous natural avalanches had recently fallen and were plainly visible to anyone traveling the back country.

Accident Summary

The 15th Annual Leadville Winter Carnival was scheduled for Saturday and Sunday, February 24 and 25. The highlight of the carnival was a 30-mile cross-country snowmobile race planned for Sunday. On Saturday morning, the 24th, a group of five snowmobilers headed west from Leadville to pack the trail for Sunday's big race. They had traveled about 8 miles west of Leadville, going past Turquoise Lake, and were about 1½ miles up the old Carlton Tunnel road when Dean Keas, one of the drivers, had trouble with his machine. Joe Goddard stopped to help; the other three machines continued up the road grade on a steep mountainside.

Shortly, the two men got Keas' machine started, and they then proceeded uphill with Goddard in the lead along the trail broken by the first three vehicles. When the two men were partly up the trail, a small slab released above Goddard sweeping him and his machine off the trail. More snow was dislodged as man and machine tumbled downhill.

The avalanche ran about 100 yards down the slope before coming to a halt. There was no sign of Goddard. His four companions rushed to the rescue but could still find no clues. One of the men then hurried back to Leadville to summon help.

Rescue

At the time the alarm was sounded, scores of persons preparing for the weekend activities were on hand to help with rescue efforts. Working with probe poles, the rescuers located the body of Goddard at about 1415. Buried for more than 3 hours under several feet of snow, the victim was dead from suffocation.

This tragedy smothered the spirits of the weekend's festivities. In condolence, the race committee cancelled the race and donated the $1,500 snowmobile race purse to Goddard's widow.

Avalanche Data

This avalanche was a small slab that was triggered by Goddard's snowmobile. It was but one of dozens that were observed in the area and which ran as the result of the recent snows and strong winds. Further avalanche details are not available.

Comments

This accident documents the first known snowmobile fatality caused by avalanche. The next avalanche-snowmobile fatality was not recorded until December 1970 (see No. 70-8), but as snowmobilers pursue their sport into steeper and more dangerous terrain, the number of accidents can only increase.

One of the clearest signs of avalanche danger is the presence of recent avalanche activity. On their rescue mission, the rescuers noticed numerous small avalanches on the mountains surrounding the accident site. The point to be made here is that back-country travelers should always be watchful for any signs of instability and should be prepared to alter their plans in the interest of safety.

A further note of interest in this accident is that the victim was the fourth person to drive his machine across this slope. The first three had crossed without incident, yet Goddard's machine put the overloading stress on the slope and caused failure. The point to be emphasized is that a single crossing of a slope without failure does not necessarily indicate stability. Too often it is successive passings of snowmobiles or skiers that lead to failure (see No. 65-2 in *The Snowy Torrents* and No. 68-11 in this volume for examples).

No. 68-8 Mission Ridge, Washington March 16, 1968

2 caught; 1 partly buried, and 1 buried

Weather Conditions

About 12 inches of new snow fell at Mission Ridge on March 14 and 15. High winds accompanied the snow. Because of the bad weather, the upper chairlift did not run on these two days, and no avalanche control was done.

The morning of March 16 brought mostly clear skies and light winds. The low temperature was 28°F and it warmed to 36° by early afternoon. The snow ranger and pro patrol controlled the upper slopes with hand charges and brought down several large hard- and soft-slab avalanches. The upper chairlift was opened at 1010. All areas that had not been opened were posted with avalanche closure signs. Avalanche control teams continued to work areas not open and had to post guards on some of the closed areas because of skiers violating closures.

Accident Summary

At about 1400 on the 16th, Dr. Gordon Congdon, Ray Johnson, Pauline Leedy, and Tom Sawyer, age 14, left the top of Chair 3 and headed for Squilchuck Ridge. Their purpose was to ski some untracked powder snow. To reach their destination they had to climb up about 200 feet vertically during their long traverse. The normal route to Squilchuck Ridge begins at a higher chairlift and was well marked with avalanche closure signs. The group was, therefore, skiing into a closed area but chose a route that took them around the closure signs.

The group reached an open bowl that had not been skied. Johnson entered first, skiing across and then down the fall line. He was followed by Dr. Congdon and Leedy. Sawyer had stopped to rest before entering and was the last to enter the bowl. When he had skied about 200 feet into the bowl, the snow fractured around and high above him. The first three skiers, who by now were near the bottom of the bowl, saw the slide start.

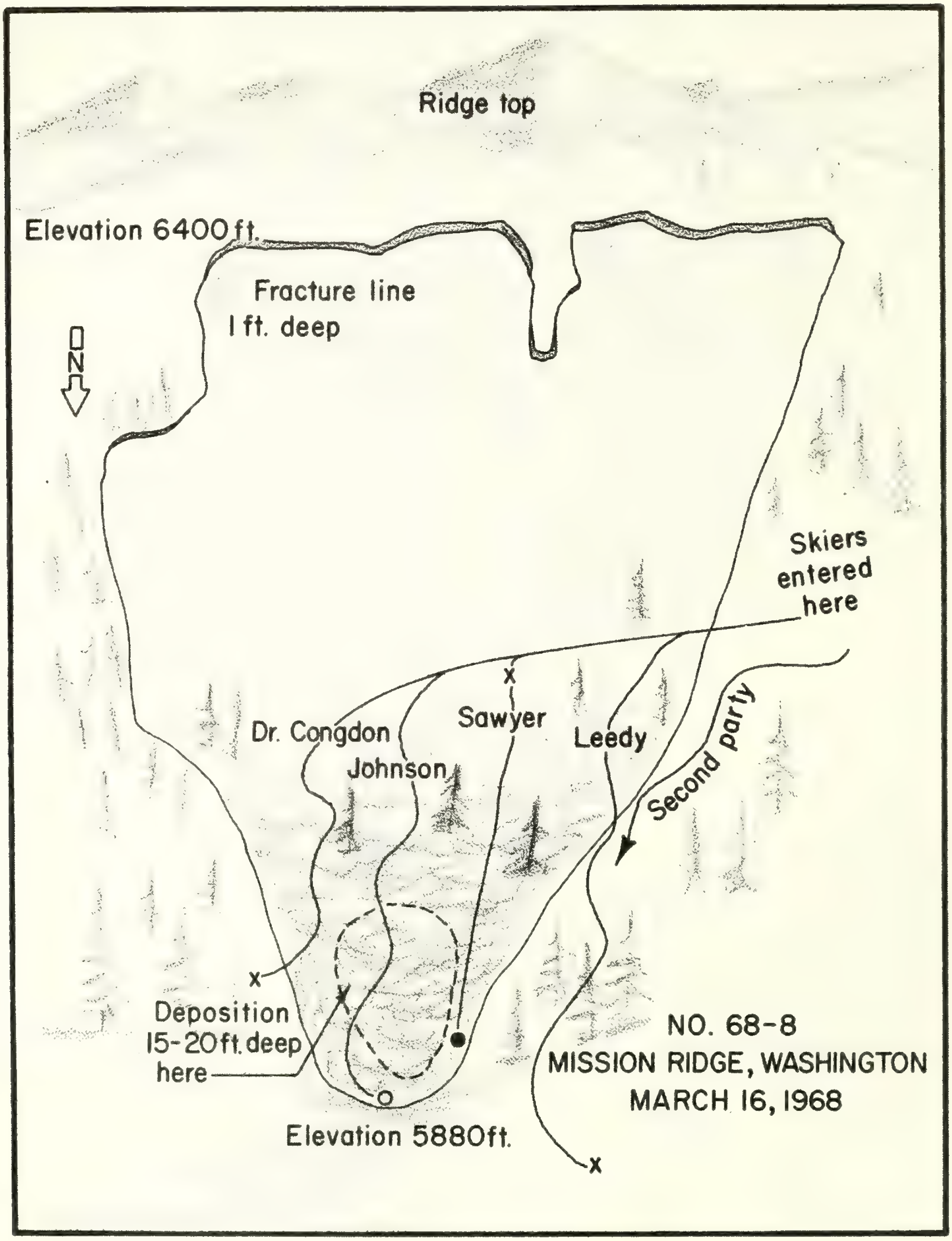
Dr. Congdon skied to the right, out of the avalanche path, and Leedy skied to the left and down into some timber below the slide path. Johnson skied behind a little knoll at the very bottom of the path thinking that the avalanche would not come that far, and if it did, the knoll would stop it. The slide flowed over the knoll, however, and buried him to his knees, immobilizing him. Meanwhile, the avalanche had knocked Sawyer down, and he was carried down the slope about 400 feet, Dr. Congdon was trying to follow Sawyer's progress in the slide, but the snow was flowing over Sawyer. Just as the slide stopped, Dr. Congdon noticed a black glove flip to the surface.

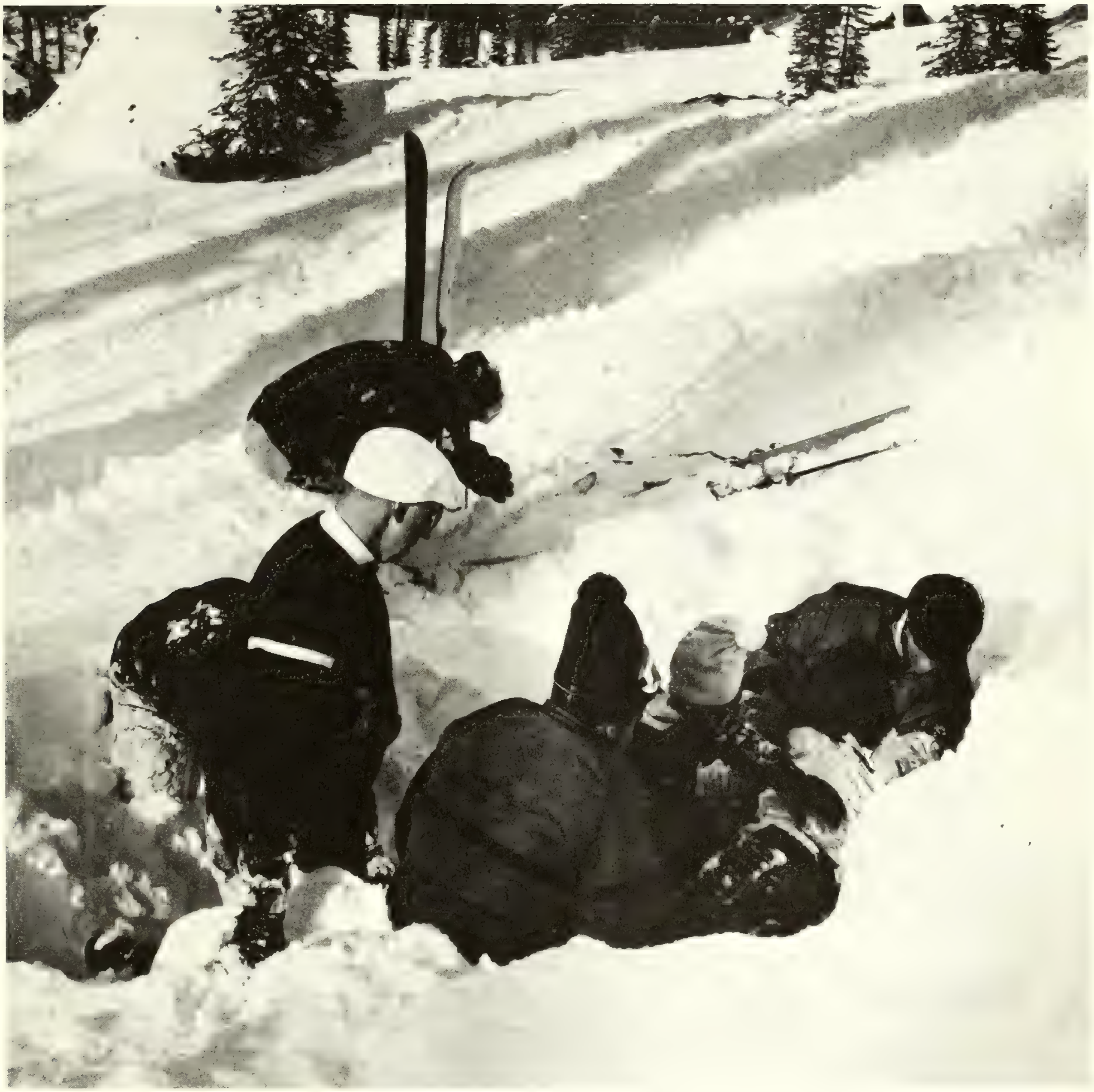
Rescue

Johnson was closer to where the glove was seen but was unable to free himself quickly from the snow. Dr. Congdon immediately skied around the lower end of the slide and worked his way back up to the glove. He reached the victim in 3 to 5 minutes and frantically began digging him out. Sawyer's hand was the only part of his body that was not buried, and his arm was fully extended toward the surface. His head was about 3 feet beneath the surface. Upon getting Sawyer's arm and head uncovered, Dr. Congdon immediately began mouth-to-nose resuscitation. The victim was unconscious and blue from lack of oxygen.

Meanwhile, another party of skiers, which had been following the tracks of the first, saw the slide start and hurriedly skied toward the avalanche. Dr Congdon shouted for help and they quickly skied over. One of the members of this group was a professional photographer who shot some excellent photographs to document the rescue effort.

After being freed from the snow, Sawyer quickly began breathing on his own and regained consciousness. He had suffered no injuries in the slide. He had lost one ski pole, but his skies were still intact on his feet. He skied back to the Mission Ridge Lodge with the group, and the slide was reported. The entire rescue had taken little more than 10 minutes.


Ridge top
Elevation 6400 ft.
Fracture line
1 ft. deep
N
Skiers
entered
here
Dr. Congdon
Sawyer
Leedy
Johnson
Second party
Deposition
15-20 ft. deep
here
Elevation 5880 ft.
NO. 68-8
MISSION RIDGE, WASHINGTON
MARCH 16, 1968



No. 68-8. Mission Ridge, Washington. This remarkable photograph was taken only minutes after the victim was uncovered. Mouth-to-nose resuscitation has been applied, and the victim has just begun breathing on his own. Minutes later, he was able to ski away under his own power. Photo by Forest & Whitmire Photography, Yakima, Washington.

Avalanche Data

This avalanche was a medium-sized soft slab classified as SS-AS-3. The fracture line was about 1 foot deep and 800 feet long. The slide ran about 1000 feet slope distance, and about 500 feet vertical.

The slope on which the slide occurred was at an elevation of 6200 feet with a north-northwest exposure. The slope angle was 40° in the 200 feet, 33° in the middle 400 feet, and 24° near the bottom with a slight depression at the bottom. The fracture line was on the 40° portion of the slope. Because of the depression at the bottom, debris was as deep as 20 feet in places. Where Sawyer was buried, the debris was 8 feet deep.

Comments

Several of the members of the group that triggered the slide had been previously warned about skiing past closure signs. One member had stated earlier that he thought the Forest Service and ski patrol were wasting time and money on explosives and control work. After the accident, he admitted he was wrong. In this case, the group had not skied past any signs but had known the area was closed. They had climbed uphill from a lower lift to avoid the signs. One member of the second group of skiers, a ski instructor, had also been warned about skiing around closures. Had the first group not been caught by the slide, the second group might have been the victims.

This accident points to the need of strictly enforcing closures with restrictive measures for violators. Secondly, to improve public relations, demonstrations of control techniques or even invitations to selected individuals to accompany and observe control work might be helpful. This might convince some skeptics of the need for this work.

Very good fortune saved Sawyer's life. He would never have been found in time had one hand not been extended to reach the surface. And after he was found, he was fortunate to have a doctor immediately give resuscitation. Finally, he was fortunate to have been carried outside the deepest deposition area. If he had been more in the center of the slide, he would have been buried in the deepest part of the debris. It is unlikely that any part of him would have remained exposed.

The black glove was the only—and vital—clue that led to quick and successful rescue. In this case, the glove was easily visible, but in other accidents (for example, see *The Snowy Torrents* No. 64-2), clues have been present but barely visible. This underscores the importance of a thorough hasty search for surface clues. Often enough, inexperienced parties have left the scene too quickly to seek help. The buried victim's chance of survival diminishes quickly in these cases.

6 caught; 2 partly buried and 2 buried; 1 killed

Weather Conditions

The first 5 days of March 1968 at Mammoth Mountain Ski Area were clear and mild. Temperatures ranged from the midtwenties at night to the low fifties in the afternoons. On the night of the 5th, an ice crust formed on all exposures, and snow began falling the following day. Ten inches of snow had accumulated when the storm ended on March 7.

Four days of clear, mild weather followed, and it was noticed that surface hoar had formed on north exposures on the upper mountain. Snow began falling on the night of March 12 and totaled 16 inches by the night of the 13th. The weather remained cloudy and cool until the 16th when 8 more inches of snow fell. Sunday, March 17, dawned overcast and cool.

Accident Summary

Avalanche control work began early on the morning of the 17th. A control team of four Mammoth Mt. patrolmen left the top of the gondola and headed west along the ridge locally referred to as the Cornice. Hand charges were thrown in the chutes off the Cornice, releasing several small sluffs. The team had covered ¾ of a mile along the Cornice when they arrived at the top of a slope that is now called Scottie's Run. By now they had run out of hand charges and had seen no evidence of major instability. Because there were no clear signs of instability on previous slopes, the group believed Scottie's would be safe also. The four members of the control team skied Scottie's Run without incident, confirming their belief that the snow was stable. (The size and steepness of this slope are such that the patrol would never have ventured upon it had they felt it to be unstable.) When all control teams had finished their work, the upper mountain was opened for skiing at about 1130.

At about 1400, a group of 10 skiers skied west along the Cornice seeking the powder snow on Scottie's Run. The group enjoyed a great powder run and then skied down to the gondola to get in another run on Scottie's.

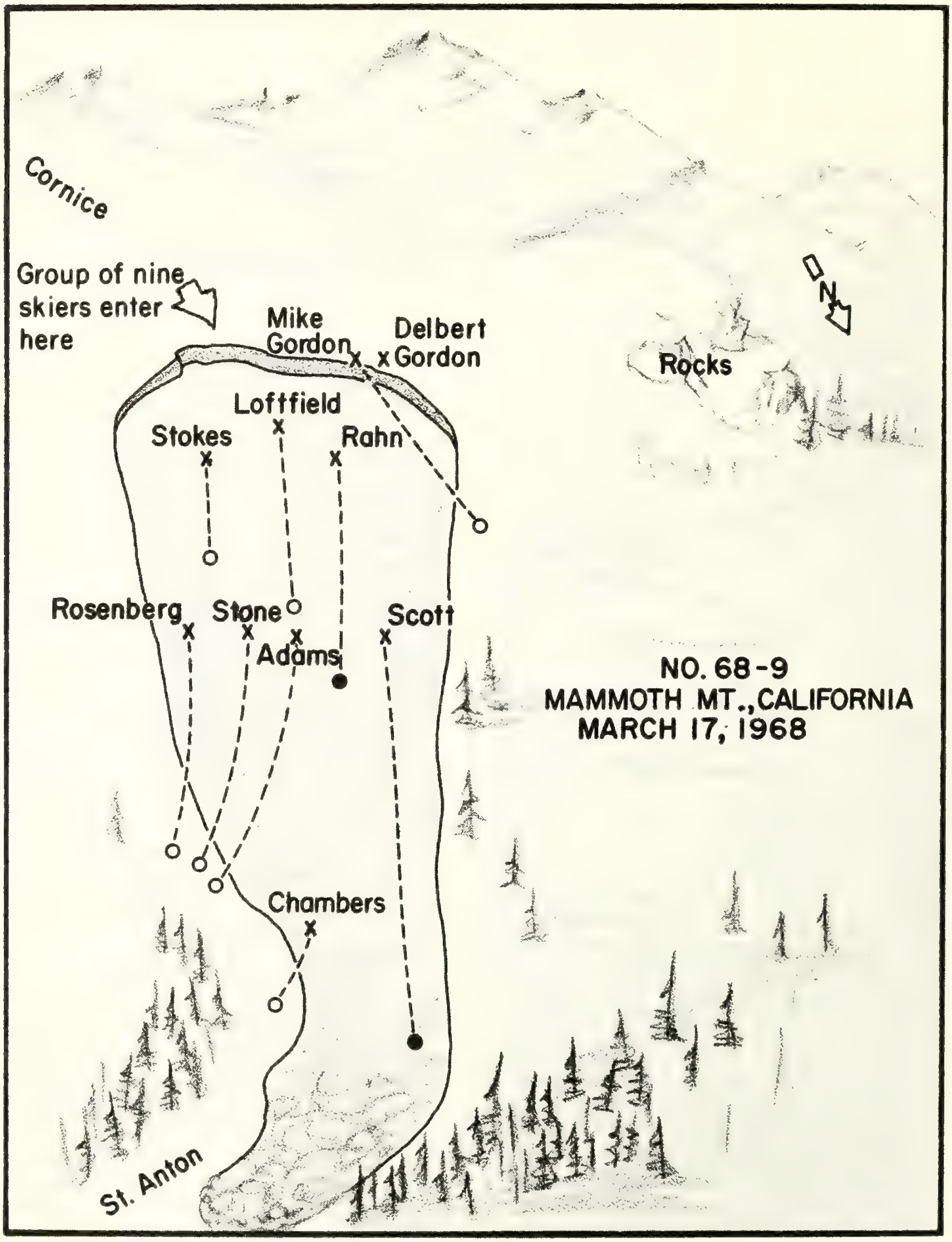
On the next run down shortly after 1500, the group consisted of nine skiers. Four men, including Clifford Scott, skied about two-thirds of the way down Scottie's and stopped. The other five skiers started in at the top of the slope and had skied about one-third of the way down. Delbert Gordon and his son, Mike, were the last members of this group, with Mike slightly behind and below his father. They were both traversing the upper part of the slope when the snow fractured beneath Mike's skis. He was caught but managed to "body surf" to safety on the side of the slide; his father was not caught.

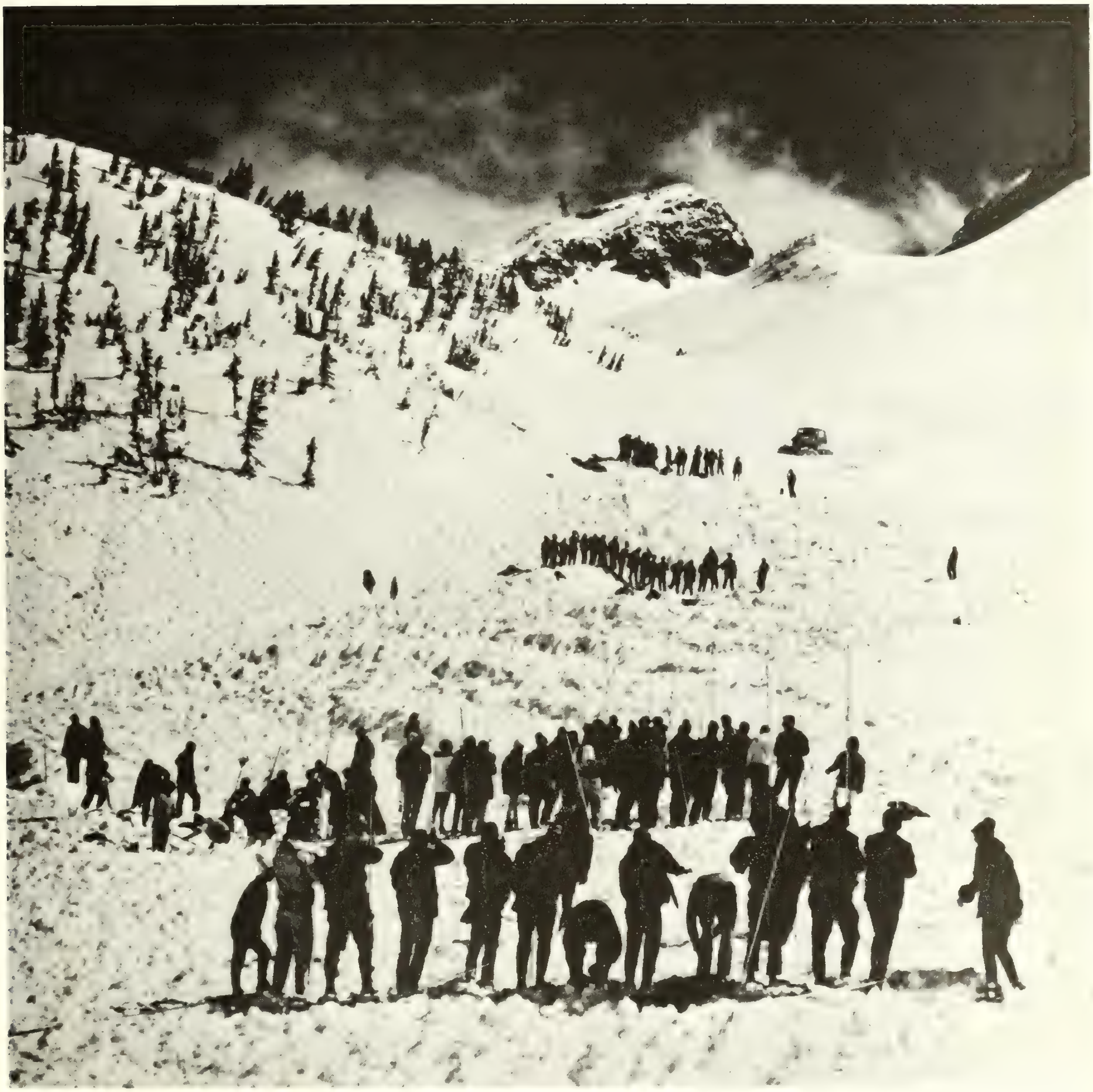
Bob Rahn, who was with the upper group of skiers, heard a sound like a thunder clap and looked uphill to see the avalanche just beginning to move. He was quickly engulfed in the moving snow but managed to stay on top by breast stroking. When he came to a stop he was buried by snow from behind him, but he immediately stuck a ski pole upward and covered his face with the other hand thus creating an air pocket for breathing. He was quickly located by his ski pole and dug out unharmed from beneath 2 feet of snow.

Roger Loftfield also was in the upper group of skiers and was trapped in the center of the slide. He was knocked down and rode the slide on his back, being carried more than 600 feet downhill. He came to rest only partly buried and was able to free himself.

Near the bottom left of the slide path and at the head of St. Anton Gully, another person not with the group, Sally Chambers, had just picked herself up from a fall when she heard someone say, "Oh no!" She turned around just in time to see a wall of snow descending upon her. With no chance to move, she was immediately overwhelmed by moving snow and carried on a 300-foot ride. While immersed in the turbulent snow, she had great difficulty breathing. She came to rest partly buried and was able to dig herself out; she had lost most of her ski equipment.

Meanwhile, the four skiers who had been first down Scottie's were spread out on the lower part of the run. Although no avalanche sounds were heard by this group, one of them


Cornice
Group of nine skiers enter here
Mike Gordon
Delbert Gordon
Rocks
N
Loftfield
Stokes
Rahn
Rosenberg
Stone
Scott
Adams
NO. 68-9
MAMMOTH MT., CALIFORNIA
MARCH 17, 1968
Chambers
St. Anton



No. 68-9. Mammoth Mt., California. Probe lines searching for the victim on St. Anton on March 18. The avalanche flowed from right to left in this photograph.

saw the avalanche and shouted a warning to the others. Three of them managed to get to higher ground, but Clifford Scott was forced into the draw on St. Anton. He was buried under moving snow.

Rescue

After freeing themselves, the group quickly determined that only Scott was missing. One member left the slide area and skied to the bottom to summon help; the other seven began looking for Scott.

Assistant patrol leader, Tom Landauer, was on top of the mountain just after the avalanche occurred and was quickly on the scene. A scuff line made up of available people began searching for clues in the area where Scott was last seen. Meanwhile, at about 1535, the avalanche was reported at the bottom of Chair 3 by two other skiers who had witnessed the slide. The ski patrolman at the top of Chair 3 grabbed the hasty search pack stored there and skied to the accident site. At about the same time, the avalanche was reported to the patrol room at the base area. Snow Ranger Stan Bunce and two patrolmen left by snow cat with a hasty search pack and probe poles. When he arrived, Bunce took over as head of the hasty search.

At 1635, Clifford Scott was found under 4½ feet of snow by the hasty probe line. Mouth-to-mouth resuscitation and external heart massage were given but with no response from the victim. Revival efforts were continued as the victim was transported by snow cat and then by ambulance to the hospital where Scott was pronounced dead from suffocation.

Meanwhile, at the accident site, an unidentified cap was found on the debris and two skiers were reported missing at the bottom of the mountain as the day ended. Because of the chance that more victims may have been buried in the avalanche, the rescue was continued. Probe lines were maintained through the night until 0230 on March 18. At that time, all rescuers were removed because of worsening weather and the threat of another avalanche from the snow remaining at the top of Scottie's.

At 0730 on the 18th, the hanging snow at the top of Scottie's was shot with explosives, releasing a larger avalanche than the one the day before. Probing was continued and then trenching begun in the avalanche debris, but no further victims were found.

The ski area was searched for the two missing skiers with no results. The back side of the mountain was checked, but wind and new snow had erased all tracks in that area. Finally, at 1730, one of the missing skiers walked into the ski area from the back side; his companion was too tired to walk out and had remained in the canyon bottom outside the ski area. The two had mistakenly skied beyond the ski area boundary, had become lost, and were forced to spend the night in the snow. The other missing skier was shortly retrieved by snow cat.

Also late in the day on the 18th, the ski area received a phone call from a woman identifying the fur cap that had been found in the avalanche debris. When the avalanche occurred, she had been on the St. Anton run and had skied away from the slide. She had not been caught in the avalanche. All missing persons had now been accounted for, and rescue operations were ended at 1815 on March 18.

Avalanche Data

The fatal avalanche was classified as SS-AS-4. It ran 2500 feet slope distance and fell 1000 feet in elevation. The fracture line was approximately 14 inches deep on this north-facing slope, and the avalanche ran on a buried surface-hoar layer. The fracture line occurred about one-third of the way down the slope, lower than its normal release point. Hasty snow pits dug after the accident indicated that the slope fractured where the surface hoar was best developed. The only areas on the mountain that were found to have buried surface hoar were Scottie's and areas to the west along the Cornice.

The fracture line was very straight in the horizontal, and the snow had fractured directly under Mike Gordon's skis. In addition, nine skiers were on the slope at the moment of release, and 10 skiers had skied the slope only a short time earlier. The trigger, therefore, was most likely a combination of the cutting action of ski traversing and the loading and disturbance of nine skiers in the same area. This was enough to cause failure on the weakly bonded surface-hoar layer.

Comments

There is conflicting testimony and evidence concerning whether or not adequate avalanche control measures were carried out on the day of the accident. No explosives were used on Scottie's Run, but hindsight indicates that explosive control should have been carried out, this being the normal procedure.* The accident and the large slab avalanche released the following morning were dramatic signs of instability, but it cannot be determined whether the instability existed early on the morning of March 17 when avalanche control was being performed or whether it developed later in the day. Certainly, the results of explosive control early on the 17th indicated no widespread instability, for only small sluffs were released along the Cornice. Nevertheless, explosive control should have been carried out on Scottie's because this was standard procedure. The ski patrol felt, however, that the slope was stable, and so they skied it.

The method in which the patrolmen skied Scottie's is another point that was not accurately established. On the one hand, statements were made that the ski patrol had thoroughly protective skied the slope; that is, traversed the slope leaving a criss-cross pattern. On the other hand, there were statements that protective skiing was inadequately performed before it was opened to the public.

In any event, a lawsuit was filed against the ski area claiming negligence on the part of the ski area by not providing adequate avalanche control measures. The case was settled out of court, and thus, no judgment was ever made on the question of negligence. It would have been a difficult case to decide mainly because there are so many unanswered questions on snowpack stability and the effectiveness of avalanche control measures—questions that stump even the so-called "avalanche experts." Even explosive control has proven to be inadequate in certain cases when avalanches released under skiers on slopes that had previously been hand charged (see Nos. 71-13, 71-22, and 71-23 for several examples). To further complicate the problem, slopes that were stable at the time of control can become unstable later as stress in the snowpack increases with time. These are difficult problems that can only be solved after years of observation, experimentation, and research.

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* At that time there was no artillery for avalanche control at Mammoth Mt. Now, the standard control procedure is to shoot the entire Cornice area, including Scottie's, with a 75-mm recoilless rifle.

1 caught and partly buried

Weather Conditions

Forty inches of snow fell at Stevens Pass from March 24 to 30. The greatest 24-hour snowfall was 19 inches on the 28th; 10 avalanches were released on that day. Strong west and southwest winds averaged 13 m.p.h. for the storm period. (At this time, the anemometer was in a sheltered location; true windspeeds were considerably stronger.) Temperatures ranged from 27° to 34°F.

On the morning of March 30, 4 inches of new snow lay on the ground and the temperature was 22°F. The sky was clear. By 0900, all avalanche control measures including 13 rounds with the 105-mm recoilless rifle had been accomplished, and all areas were opened. Five size 1 and six size 2 to 4 avalanches had been released.

Accident Summary

At about 1235 on March 30, Dick Swanson and Al Holcomb, both from Seattle, had just unloaded from the Seventh Heaven Chairlift and were traversing across Barrier Bowl below Cowboy Mountain. Swanson was about 50 feet ahead of Holcomb when he looked uphill and saw a swirl of snow descending toward him. For a moment, he thought it was another skier but then realized it was an avalanche. The snow struck Swanson, knocked him down, and tumbled him downhill for 100 feet. The avalanche continued for another 100 feet below Swanson before stopping.

Holcomb managed to stop just short of the slide; he tried to keep his eyes on Swanson but lost sight of him for about 30 seconds in the swirling snow dust. When the snow settled, he saw Swanson was partially buried about 100 feet downhill. He called down to see if he was injured, and Swanson answered that he was all right but might need help to get out. One arm and shoulder and his head were free. After being freed from the snow, Swanson and Holcomb skied to the bottom of the mountain and reported the slide.

Rescue

Meanwhile, a chairlift operator at the top of Chair 4 also witnessed the slide and notified the ski patrol by radio. Because it was not immediately known how many victims were involved, rescue operations were initiated. A hasty party of seven patrolmen was dispatched to the scene, and a few minutes later Swanson and Holcomb arrived at the ski patrol office. Holcomb gave his account of the slide and stated that, as far as he knew, only Swanson was involved in the slide.

Just to be sure, it was decided to follow through with the search operation. A main party of 13 probers was sent to the slide site where they probed the entire area; nothing was found. The search was discontinued at 1600.

Avalanche Data

This was a small soft-slab avalanche released by a falling cornice (SS-AO-2) on the ridge of Barrier Mountain (actually Cowboy Mountain). The slide was 50 to 100 feet wide and ran 600 feet slope distance. Barrier Bowl is a northeast-facing slope with an average pitch of 30°. On the morning of the 30th, a SS-AA-4 was released from this slope. The slide that buried Swanson was apparently on the east edge of the larger slide released earlier in the day.

On March 31, a control team climbed to the ridge top of Barrier Mountain to remove the overhanging cornice. Footprints were found leading along the cornice, and at a point directly above the avalanche area, the cornice had been broken off. Evidently, two or more people had been hiking along the narrow ridge top and had broken off a soft cornice which in turn triggered the avalanche that caught Swanson.

Comments

The points of access leading to this ridge have since been posted with avalanche closure signs to prevent a recurrence of this type of accident.

No. 68-11 Mt. Hood Meadows, Oregon December 8, 1968

1 caught and partly buried

Weather Conditions

On December 4, a light rain fell over Mt. Hood Meadows and formed a rain crust. On the 7th, snow began falling and by 0700 on the 8th, 12 inches of new snow had accumulated. The temperature was 29°F, and the wind was from the southwest averaging 15 m.p.h. but gusting to much higher speeds. Lee slopes were loading heavily from wind-transported snow; 26 inches of new snow had accumulated on the north-facing Elevator Shaft slope.

Accident Summary

At about 0945 on December 8, Richard Eggebraaten and Ralph Stading left the top of Lift 1 and skied a run called the Elevator Shaft. Eggebraaten watched Stading and several others ski down, and then he started down. He made one turn and fell, and one of his skis came off. As he was putting on his ski, another skier, Greg Chamberlin, came down above him. Chamberlin made two turns above where Eggebraaten had fallen and then skied off to the right side of the slope. Suddenly the snow fractured just behind the tails of Chamberlin's skis. He made it to the side of the slope, clear of the moving snow. Stading, at the bottom of the slope, saw the slope fracture and shouted "Avalanche!" He then headed for high ground.

The snow fractured all around Eggebraaten who was standing in the center of the slope. He was immediately knocked down and engulfed by snow. Witnesses caught glimpses of him as he bobbed up and down with the avalanche. He held his hands and poles over his head as best he could but was being buried deeper as he approached the bottom of the slope. When the slide stopped, Eggebraaten was buried to the neck with only his head and arms out of the snow.

Rescue

Eggebraaten was the only skier caught in the slide, and he immediately called out for help when the snow stopped. Stading quickly skied to his aid. Another witness who was at the top of the slope and not far from the Lift 1 terminal also called for help; within minutes, two ski patrolmen skied down to help dig Eggebraaten out. He was unhurt and had not lost any equipment. The rescue was concluded at 1000.

Avalanche Data

This was a SS-AS-3 avalanche. The slide was measured to be 267 feet wide at the top, 84 feet wide at the bottom, and 253 feet long. The fracture line was 26 inches deep and had fractured down to the rain crust which had formed 4 days earlier. Debris was 14 feet deep in places.

The Elevator Shaft slope has a pitch of 40° and has a convex curvature in the starting zone. It is relatively smooth, is free of trees, and has a north exposure. The top is at an elevation of 6600 feet.

Comments

The past avalanche history of this slope is not known, but its steepness, openness, and aspect all indicate that it should present an intermittent hazard. The slope was skied the day before and was ski checked by the patrol on the morning of the accident. Two comments can be made about this.

First, the slope is too large and dangerous to ski check after storms. Hand charging is a much safer method of checking this slope. Second, a slope is not necessarily stable if one or two ski passes fail to release an avalanche. It is not uncommon for the second, fifth, or even twentieth skier entering a slope to release a slide. It is the instability of the slab layer that dictates whether the first or subsequent skiers will create enough stress concentration to cause failure and avalanche release.

No. 68-12 Slide Mountain, Nevada December 27, 1968

1 caught, buried, and killed

Weather Conditions

A storm had moved into the Sierras on December 24 bringing snow and strong west winds. The storm intensified on the 26th, and heavy snow fell and continually strong winds blew on the 26th and 27th.

Accident Summary

On December 27, a group of six college students from Carson City, Nevada, home for the Christmas holidays, planned a day of skiing and a downhill cross-country run at Slide Mountain. The group consisted of Pat Glenn, 18; David Heckathorn, 18; Scott Jones, 18, Bill King, 18; Scott Mattheus, 19; and David Ross, 19.

The members of the party arrived at the Mt. Rose Ski Area to ski in the morning. At 1215 they met at the top of the T-Bar lift and left the ski area. The party made a long climbing traverse along the west side of Slide Mountain. After reaching the 9300-foot level at the edge of the timber, they stopped to eat lunch at 1330.

The weather at the time had deteriorated quite rapidly because of a storm intensifying from the west. The wind was estimated at approximately 45 to 50 m.p.h.

After lunch the party planned to ski down the south side of Slide Mountain into Ophir Creek.

At this time the party became separated. Ross had his skis on first after lunch and started out, with King and Jones following moments later. Glenn had trouble with his bindings so Mattheus and Heckathorn stayed to assist. Visibility had become very limited by blowing ground snow.

After skiing down 150 to 200 yards, King and Jones could not see Ross; they decided to wait for the rest of the group. They thought that Ross had done the same in the lee of one of the small rolling ridges. In a few minutes the rest of the party rejoined King and Jones, and they all started down looking for Ross. The snow cover was very thin in some places because of the southern exposure and prevailing winds on that side of the mountain. Skiing conditions were poor; thus, the party made fairly slow time. As they reached the 8600-foot level, they had not seen any sign of Ross and had begun to call out and look for him. About the same time they skied into what they thought was a small "old" avalanche and did not pay too much attention to it. They had, however, started some fracturing and small slab movement on the steeper slopes but did not connect the two situations.

They continued down to Ophir Creek and still there was no sign of Ross. They thought that he was still ahead of them and that he was going down to Price Lake. They were not too concerned about not seeing any ski tracks: the strong wind and blowing snow were erasing their own tracks within minutes.

When the party arrived at Price Lake at 1500, there was still no sign of Ross. They rested a while at the lake thinking maybe they had passed him along the way. After calling and looking around the solidly frozen lake, they continued down toward U.S. Highway 395.

They reached the highway at 1815 where they were met by David Ross, Sr. Together they conducted a road search which produced nothing. Finally they returned to Carson City and notified the National Ski Patrol and the Washoe County Sheriff's Office.

Rescue

The five boys in the party were closely interrogated by the ski patrol and sheriff's office. The route taken by the group was mapped out, and it was learned that Ross was equipped for an overnight stay if necessary. It was decided to conduct a surface search the following morning with the hopes that Ross had become lost or injured and was spending the night on the mountain.

On Saturday morning, December 28, the search began with 21 patrolmen and 6 volunteer skiers. In addition, the Nevada Search and Rescue group provided several 4-wheel drive vehicles for getting close to the area. Several skimobiles, one snow cat, and two air-planes were also used. Low clouds limited the air search, but visibility was good for the ground search.

The route of the ski party was followed but no tracks or clues were found. The one avalanche along the route and near the place where the boys had lunch was not probed. No surface clues were found in the avalanche debris.

The surface search was continued on Sunday the 29th. The rescue leader still felt there was a chance of survival so a larger area was covered, and a helicopter was added to aid the air search. During the night of the 28th, various reports were phoned in: a campfire sighted on Slide Mt. to the north; a light seen on the Slide Mt. avalanche chutes; and smoke seen in Davis Creek Canyon, near the search area. All these were checked out with negative results.

During the course of the search, various rumors began growing that Ross was not with the tour group at all or that he had skied out and left town without telling anyone. The five boys were again questioned, and it was ascertained that Ross was with the group and was most likely still missing on the mountain.

It was decided to continue the search. Fifty-five volunteers searched the area on the 30th and 31st and found nothing. At dusk on the 30th, the helicopter crew reported sighting what they thought was a pair of skis stuck upright in the snow, but this turned out to be an incorrect report. It was finally decided that a "last ditch" probe search of the avalanche debris would be carried out the following day.

On New Year's Day, January 1, 1969, 24 patrolmen assembled at the avalanche site on Slide Mt. Probe lines were begun at 1230. At 1420, one of the probers called the group leader over to check on what he had struck. After making a few probes, the leader thought they had found the missing skier and told them to start digging.

At 1430, David Ross' body was uncovered in the debris. He was found 4 feet beneath the surface, lying on his back with his head uphill. There was a 2-inch-thick ice mask around the face and body. The Washoe County Coroner's report later indicated Ross had died of suffocation and most likely had died within two hours of being buried.

Avalanche Data

The avalanche occurred on the south slope of Slide Mountain at the 8600-foot elevation on a 30° slope and about ¾ mile above Price Lake. It was a small slab avalanche that was probably triggered by Ross. Only a thin layer of snow covered the slope; a scattering of low sagebrush and some small willows grew on the slope.

Wind slab had been deposited on an old sun-crusted layer. There was little cohesion between the slab and the crust, thus providing a good sliding surface. The depth of the fracture is not known; however, the debris was a maximum of 10 feet deep and averaged between 5 and 6 feet deep. The slide had an estimated length of 300 yards.

Comments

Concern about avalanches was not on the minds of the members ot this tour group. The five surviving members gave little thought to the avalanche when they first came upon it. They also showed little concern to the small slabs they released themselves.

A basic rule of safety in ski touring is that the members of the party not lose sight of one another. This party violated this rule and it proved fatal. The slide occurred only a few hundred yards from where the boys had stopped for lunch; however, the site was over a slight ridge and not visible to the others who were a few minutes slower than Ross in getting their skis on. Had Ross remained in sight of the others, there is a chance that he might have been located and dug from the slide in time to save his life.

There was also undue delay in probing the slide site by the rescuers. Even though it would not have saved the victim's life, several days of futile surface searching could have been saved. Viewed from the rescuers' standpoint, the avalanche had crossed a possible route taken by the missing skier; this alone is enough to warrant probing. Even though the rescuers were correct in pursuing the hope that Ross was lost or injured and perhaps still alive, the need for a few hours of probing (for an almost certainly dead avalanche victim) was indicated by the evidence.

No. 69-1 Bighorn Mountains, Wyoming January 8, 1969

2 caught, 1 partly buried

Weather Conditions

Snow began falling in the Bighorn Mountains in north-central Wyoming on January 6. From January 6 to 8, 21 inches of snow fell at Burgess Junction (elevation 8200 feet), located about 30 air miles due west of Sheridan. Heavier snow probably fell in the higher elevations around Medicine Mountain west of Burgess Junction. Temperatures ranged from 38° down to -4°F at Burgess Junction during the storm period.

Accident Summary

Alternate U.S. Highway 14 west of Burgess Junction is closed in winter, but this route over Baldy Pass is popular with snowmobilers. On January 8, three men—Milo Cooper, Ralph Hilton, and Bob Small—were traveling east by snowmobiles approximately along this route. At 1400 they were near the Medicine Mountain Observation Point and were traversing the upper part of a broad slope. Hilton was in the lead, Cooper was about 500 feet behind him, and Small was another 500 feet behind Cooper.

Hilton suddenly felt his snow machine begin to settle as if it were breaking through a crust. He quickly realized, though, that the snow was breaking away from the mountainside and that he was in an avalanche. An area 800 feet wide had begun to slide!

Hilton gave his machine full throttle and headed for the edge of the slide. His machine suddenly pitched over, but he landed on his feet and scrambled to safety out of the moving snow. Small, who was bringing up the rear, escaped the slide altogether.

Cooper was not so fortunate. He was in the middle of the slope when the avalanche began, and both he and his machine were carried downhill. He was quickly submerged in the moving snow and found it to be very quiet and much like being under water. He remembered from an avalanche school he had once attended that avalanche victims should try to swim with the slide. He began to move his arms and felt his body respond to the swimming strokes as much as it would in water; he was even able to guide himself directionally in the snow. He came to rest just barely covered with snow and was able to dig himself out almost immediately. After being carried about 400 yards, Cooper emerged unhurt from his ordeal. His machine had come to rest above him and was undamaged.

The three men were able to continue their trip, arriving at Bear Lodge near Burgess Junction later that day. They reported the slide and also four more they had seen on the remainder of their journey. Other snowmobile travelers were alerted to the hazard.

Avalanche Data

This large soft-slab avalanche was released by the snow machines cutting across the slope. The slide was 800 feet wide and ran downslope about 1200 feet. Large blocks of snow were left near the top of the slide, but the debris in the runout was well pulverized.

Comments

As the sport of snowmobiling continues to gain popularity, it is reasonable to assume that more snowmobilers will fall victims to avalanches. Their danger is particularly acute because of three basic reasons. First, they are usually traveling in back-country areas that do not receive avalanche control and also do not become packed and stabilized by previous traffic. (Ski areas benefit from both of these stabilizing measures.) Second, the weight of their machines might cause failure on a slope that would be safe to hikers or skiers. Third, once an avalanche occurs, an organized rescue unit is usually too far away to save completely buried victims. If the victim's companions cannot find him, there is little chance of survival.

To minimize these dangers, any group should first of all be well equipped. In addition to standard emergency provisions, avalanche emergency equipment should be included. Several collapsible probe poles and one or more folding shovels are minimum requirements. It should go without saying that touring alone is risky business.

Before departing, get the latest weather and snow conditions and plan accordingly. Inform someone of your intended route and estimated time of arrival at some location. Finally, be willing to turn back and abandon the tour if avalanche activity is noted or if other signs indicate hazardous conditions. Observance of recent natural avalanches is one of the best indications of high hazard.

Route finding is very important in a safe tour. Stick to the flats, ridges, or windward slopes whenever possible. If forced to cross a dangerous-looking slope, cross one at a time. The three men in this accident exercised good judgment by maintaining a distance of 500 feet between them during their traverse. As a result, only one of them was carried away by the avalanche instead of all three.

It is interesting to note the effectiveness with which Cooper said he could swim in the slide. This prevented him from being deeply and helplessly buried in the debris. Swimming is one of the best survival techniques that avalanche victims can use.

No. 69-2 Ketchum, Idaho January 26, 1969

1 house destroyed

Weather Conditions

The Ketchum vicinity experienced unusually heavy snowfall during January 1969. At the top of Bald Mountain, elevation 8900 feet, and 2 miles south of the avalanche site, 88 inches of snow with about 8 inches water equivalent fell during two major storms between January 8 and 22. During this period, total snow depth in Ketchum, elevation 5800 feet, and 2 miles southwest, increased from 18 to 43 inches. The heaviest precipitation occurred during periods when the temperature was near freezing and included short periods of rain. Snowfall ended on January 22 and was followed by 2 days of very cold weather as temperatures ranged from 6° to -11°F. By the 24th, the snowpack at the avalanche area, a south-facing slope, was relatively dense and hard-surfaced and was about 5 feet deep in the starting zone.

During the night of the 24th, the temperature again fell below zero but snow began to fall as another storm approached. Heavy snowfall accompanied by strong south winds began late on the 25th. By 1100 on the 26th, 16 inches of snow with 1.7 inches water equivalent was recorded on Bald Mountain.

Accident Summary

The Warm Springs subdivision in Ketchum is located on the relatively level river terrace of Warm Springs Creek. The subdivision is bordered on the north by a continuous south-facing slope which rises from 5900 to 7400 feet. The slope has a vegetative cover of sagebrush and grass, and in most winters it has only a thin snowcover or is bare. However, on January 26, 1969, more than 5 feet of snow covered parts of the upper slope.

Rick Borlase's house was located on a small alluvial fan at the mouth of a small drainage of this slope. At 1145 on January 26, an area of snow estimated at 15 acres broke loose from the mountain and avalanched down the draw. The sliding snow struck the center rear of the Borlase house, collapsing the center section and carrying portions 100 feet downhill. The extreme ends of the house remained relatively intact although they were covered with snow debris estimated at 20 feet deep.

The house was unoccupied at the time except for a dog which was killed. Had it been occupied, the extent of the damage and snow deposition indicate that all occupants would have probably been killed.

Avalanche Data

This avalanche was a SS-N-3 with a vertical fall distance of 500 feet from 6400 to 5900 feet elevation. The slope averages 31°, but is steeper near the top. The fracture line was 1 to 2 feet deep, and an estimated 30,000 cubic yards of snow moved down the slope. Although the flow was nearly stopped when it reached the house, there still was sufficient force to destroy it completely.

The avalanche began with the freshly deposited snow sliding on the hard surface of the old snow, but the sliding snow dug through this surface and carried some of the old snow with it. During the period from 1100 to 1300 on the 26th many other soft-slab avalanches were released from adjacent steep slopes, but none of these reached the runout zone.

Comments

The Borlase house was not the only one threatened by destruction. Local U.S. Forest Service personnel estimated that about 25 houses were in potentially dangerous locations. (Since 1969, more homes have been built in the hazard area.) After the Borlase house was destroyed, the Forest Service advised many families to evacuate their homes; but because the houses were on private land, the Forest Service had no authority to require evacuation or to initiate avalanche control.

This situation is becoming a problem in many areas of the West as more houses and condominiums are being built in avalanche runout zones. Disasters on the scale of those in the European Alps might be possible in this country if this trend continues. Avalanche zoning of mountain property is needed to prevent the construction of buildings on threatened tracts of land.

The fact that the avalanching slope in this accident was south-facing in no way makes it less dangerous than a similar north-facing slope. Large destructive avalanches can occur on steep slopes of any aspect during or after prolonged and intense storms such as this one of January 1969. Snowstorms of such magnitude may occur only once in 10 or 20 years, but the avalanches that result are no less deadly than those that run every winter.

1 caught and partly buried

Weather Conditions

Snow began falling in the Front Range of Colorado on January 22. By the morning of the 26th, 19 inches of snow had fallen at Winter Park. A mountaintop wind measuring system on Mines Peak showed that southwest through northwest winds averaged as high as 40 m.p.h. and gusted to over 65 m.p.h. during the period from the 22nd to the 26th.

On the 26th, several feet of fresh snow had accumulated on the lee slopes of Niwot Ridge, located 12 miles north of Winter Park. Snow was still falling in flurries with the temperature holding around 20°F. West-southwest winds averaged about 25 m.p.h. during the day.

Accident Summary

Twenty-six-year-old twin brothers, Darryl and Darvel Lloyd, were students at the University of Colorado and were doing research work for the Institute of Arctic and Alpine Research. On Sunday, January 26, they were hiking back to the research station on Niwot Ridge west of Boulder after visiting a research site on Isabelle Glacier earlier in the day. At about 1600, they were climbing up a rocky ridge until it became too steep and seemingly impossible. Against their better judgment, they decided to cut across a steep, snow-filled chute that was about 50 feet wide.

With no rope for belay, Darvel entered the chute after first instructing Darryl to stay on the side and watch his progress. With his first step, he immediately went into deep, soft snow up to his waist. About a third of the way across, Darvel suddenly felt the snow begin to move! The snow had fractured about 50 feet above him, and he found himself riding atop a large slab. He was carrying an ice axe which was of no use to him now, so he spread-eagled himself on the slab, feet downhill.

Darvel had traveled several hundred feet this way when the slab, having gained considerable speed, began to break apart. He was quickly submerged in the moving snow and tumbled over, head downhill. A few seconds later, he was rolled over again to a more stable position near the surface with his feet downhill. When the avalanche stopped, he was only partially buried and was able to free himself. Darvel had taken an incredible ride down the whole length (1200 vertical feet) of the narrow chute. He had suffered no broken bones or cuts. His only injuries were a serious bruise on one knee and minor bruises on the other knee and elbow. He was very fortunate that he was not struck by his ice axe which was attached by a strap to his wrist and was flipped about by the moving snow.

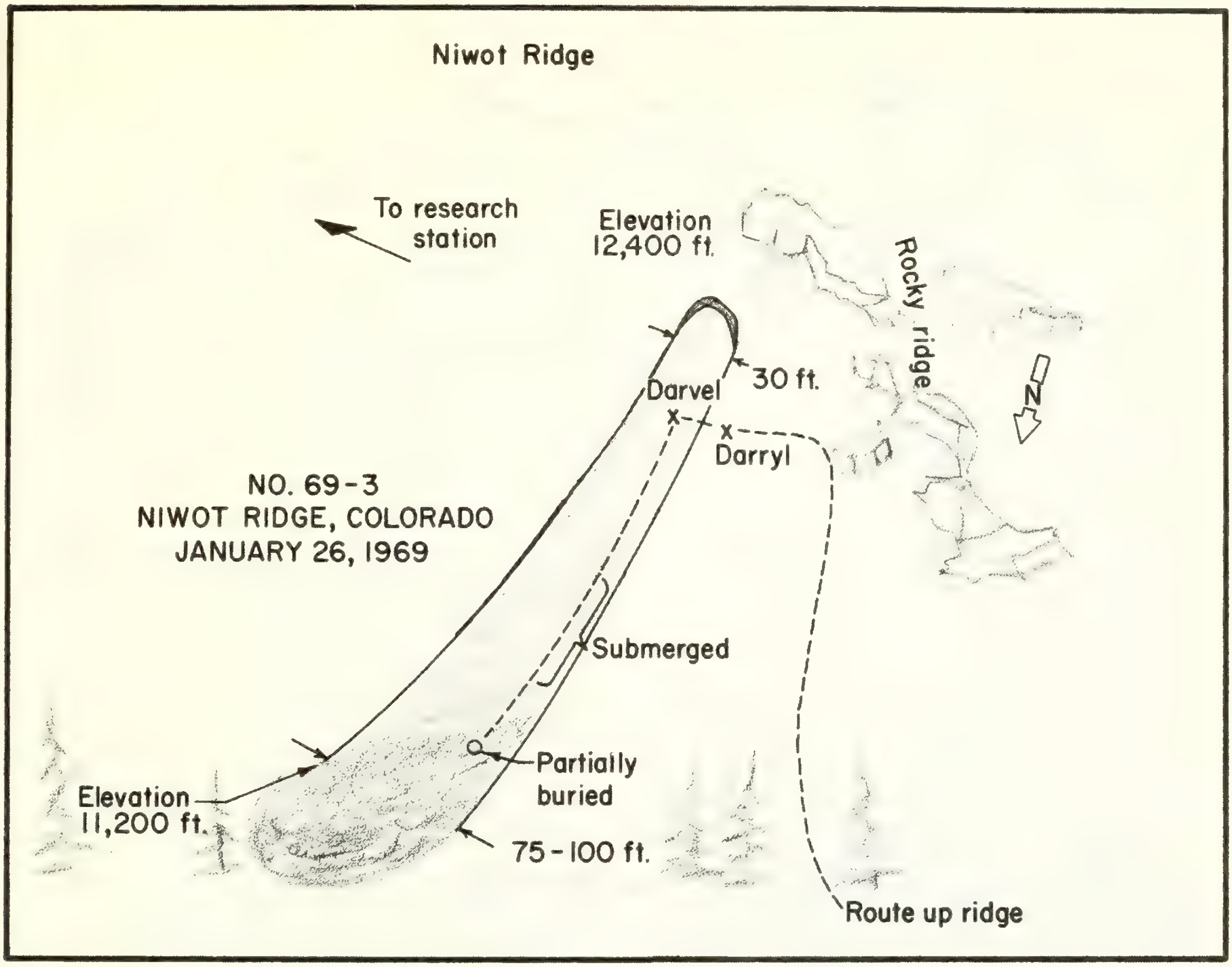
Darryl had started to slide down the cleaned-out chute to help his brother, but Darvel assured him that he was all right. Darvel then climbed back up the ridge, and both men then continued to the ridgetop and then to the research station.

Avalanche Data

This avalanche was classified as SS-AO-4. The fracture line was 2 to 3 feet deep, was 20 to 30 feet wide, had a zigzag shape, and occurred 50 feet from the top of the chute. The chute itself is a straight, even slope averaging 40°. It is a north-facing gully about 20 feet wide at the very top and 75 to 100 feet wide at the bottom. It lies entirely above timberline, starting at an elevation of 12,400 feet and ending at 11,200 feet. The avalanche slid on an old snow surface in the top half of the track and dug down to the ground in the lower half. This being a high-elevation, north-facing chute, it is very likely that depth hoar had developed earlier in the winter, contributing to the instability of the slab.

Comments

Crossing this chute without a belay was unwise, and both men, having mountaineering experience, knew it. They decided to gamble, and they lost. Climbing rope should have been included in their emergency gear. When faced with crossing a snow-filled chute, mountaineers first should be on belay and second should cross as high as possible. Thus, if the



avalanche is triggered, most of the sliding snow will be below the victim. This is desirable for two reasons: first, less strain will be put on the belay; and second, should the belay fail, the victim stands a smaller chance of a deep burial.

1 caught and partly buried

Weather Conditions

On January 24 and 25, light snow fell over the Crystal Mountain Ski Area with a total of 5 inches being recorded. Southwest winds averaging 23 m.p.h. but gusting to 35 m.p.h. blew during this period. Ski checking and hand charging on Saturday the 25th produced a lot of fracturing and settling in place but no avalanching.

Accident Summary

On Sunday, January 26, four members of the Crystal Mt. patrol had skied to the Angle Ridge-Paradise Rocks area to blast a cornice and hand charge and ski check several chutes. The control team had blown a section of the cornice which in turn had released a small soft slab on the slope below. At about 1100, one patrolman, Dieter Oberbichler, skied under the remaining portion of the overhanging cornice to determine where the next cornice shots should be placed. He had done this many times before and did not consider this to be an unsafe practice. The slope was fairly wide at this point and not overly steep, about 27°; Oberbichler believed he could ski out of any small slide that might release. He removed his pole straps but left his ski safety straps attached.

When Oberbichler was about 20 feet below the cornice and on an area of the slope that had not slid, the snow fractured near the base of the cornice. The sudden release took him by surprise and knocked him off his feet. He had no chance to ski out of the slide and was swept downhill on top of the sliding snow. At a point where the slope funnels into a narrow chute, he was carried over the brink of a steep transition and into the chute. He hurtled down this 60° chute and skimmed over the tops of several small trees. Where the slope abruptly levels out at the bottom of the chute, Oberbichler came to rest in an almost standing position, buried to the neck.

The three other members of the control team skied down to Oberbichler's aid and dug him out in 15 minutes. He was still gripping his ski poles; his skis had come off but were still attached to his feet by safety straps. He had been battered by his windmilling skis but had sustained no serious injuries. Oberbichler skied away from this accident only slightly the worse for wear.

Avalanche Data

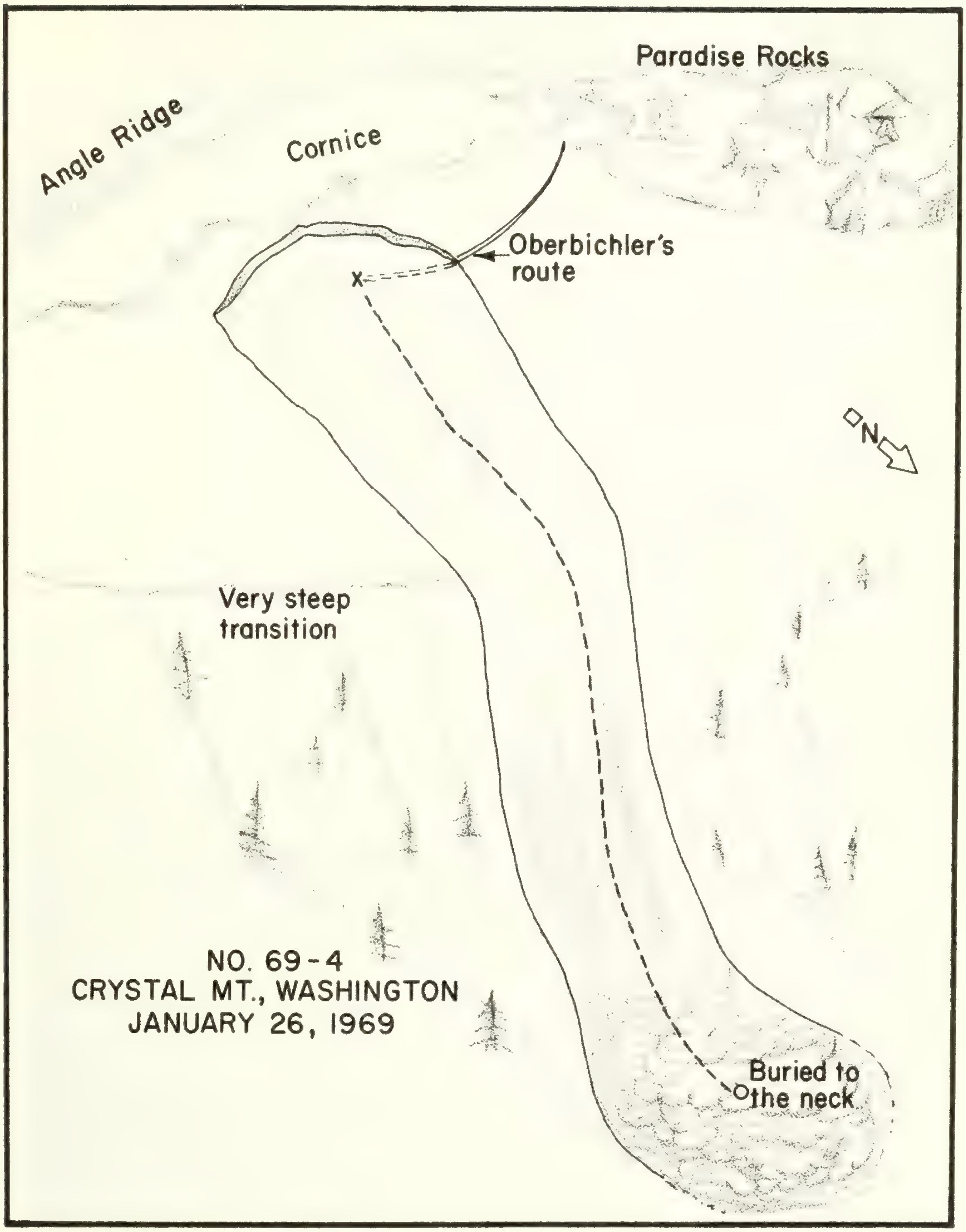
This avalanche was classified as SS-AS-2, fracturing 1 foot deep along a 75-foot-wide front. This was a northeast-facing slope that had been loaded by snow transported by strong southwest winds. The starting zone was a broad area having a steepness of 27°, but the middle track funneled into an ultra-steep chute of 60°. The small soft slab avalanche ran 400 feet vertically down this chute.

Comments

This accident reveals the capricious nature of many avalanche paths. Although Oberbichler had skied beneath this cornice numerous times before without incident, this time the slope reacted to his presence. A clue to the slope's instability on this day, however, was the small slab avalanche that released moments earlier under the impact of the falling cornice blocks.

This accident reveals also that an avalanche man, even if he is fully prepared for the slope to fail, can be caught and rendered helpless before being able to react. Oberbichler did not remove his ski safety straps because he wanted to have every opportunity to ski out of any avalanche that might release. The slope was broad, open, and not too steep, and he felt confident he could ski out of any trouble. Yet he was caught unprepared (Oberbichler later said he was looking downhill the instant the slab fractured above him) and carried on a harrowing ride that could easily have proved injurious.

Avalanche work is dangerous enough without taking unnecessary risks. Oberbichler should have been on belay, a safety precaution that should be observed whenever an avalanche worker skis onto a slope that could produce a long downhill ride.


Paradise Rocks
Angle Ridge
Cornice
Oberbichler's route
x
N
Very steep transition
NO. 69-4
CRYSTAL MT., WASHINGTON
JANUARY 26, 1969
Buried to the neck

1 caught and buried

Weather Conditions

Through December 1968, snowfall at Loveland Basin had been slightly better than half of normal. Temperatures had been cold and the winds strong during this period, and an extensive underlying layer of depth hoar had formed on all north-facing slopes. On January 22, 1969, a major storm moved into the area (same storm as in No. 69-3). By the morning of the 27th, 35 inches of snow having 2.5 inches of water equivalent had fallen at Loveland Basin. Twelve inches of this fell during the night of the 26th. The morning of the 27th brought light wind and snow and a temperature of 4°F which warmed to 24° by afternoon.

Accident Summary

Before opening Chair Lift 1 to skiers on Monday the 27th, protective skiing was carried out on Upper and Lower Tiger's Tail, Busy Gully, and Cat's Meow—the steep, popular runs served by this chair. The snow on these runs was judged to be stable. Avalanche Bowl and Zoom ski runs were not opened because there had not been time enough to test ski them.

At about 0955, five skiers, including Mrs. Ann Eberle, left the top of the chair and headed for Busy Gully to ski the powder. The group came to the top of the trail; three of them entered the run, made several turns, and stopped part way down. Then Eberle skied down and traversed along the tracks of the earlier skiers. The fifth skier skied down past her.

As Eberle was traversing to her right, the snow fractured 100 feet uphill from her in the trees above the ski run. She screamed when the avalanche hit her. The other skiers in the group instantly looked uphill, but she was almost immediately lost from sight. She was the only skier caught in the slide, and when the snow stopped moving there was no sign of her.

Rescue

As soon as the four survivors realized Eberle was buried in the slide, three of them climbed up to begin probing the debris while the fourth skied to the base area to report the slide. Instructions were also shouted to skiers riding the chairlift immediately overhead to report the slide at the top chair terminal. Two pro patrolmen were skiing within shouting distance of the chair, and the message was relayed to them by the chair riders. They arrived at the accident site only 2 or 3 minutes after the slide. Four others arrived minutes later, and these nine, headed by patrolman Sam Stevenson, formed the initial rescue party.

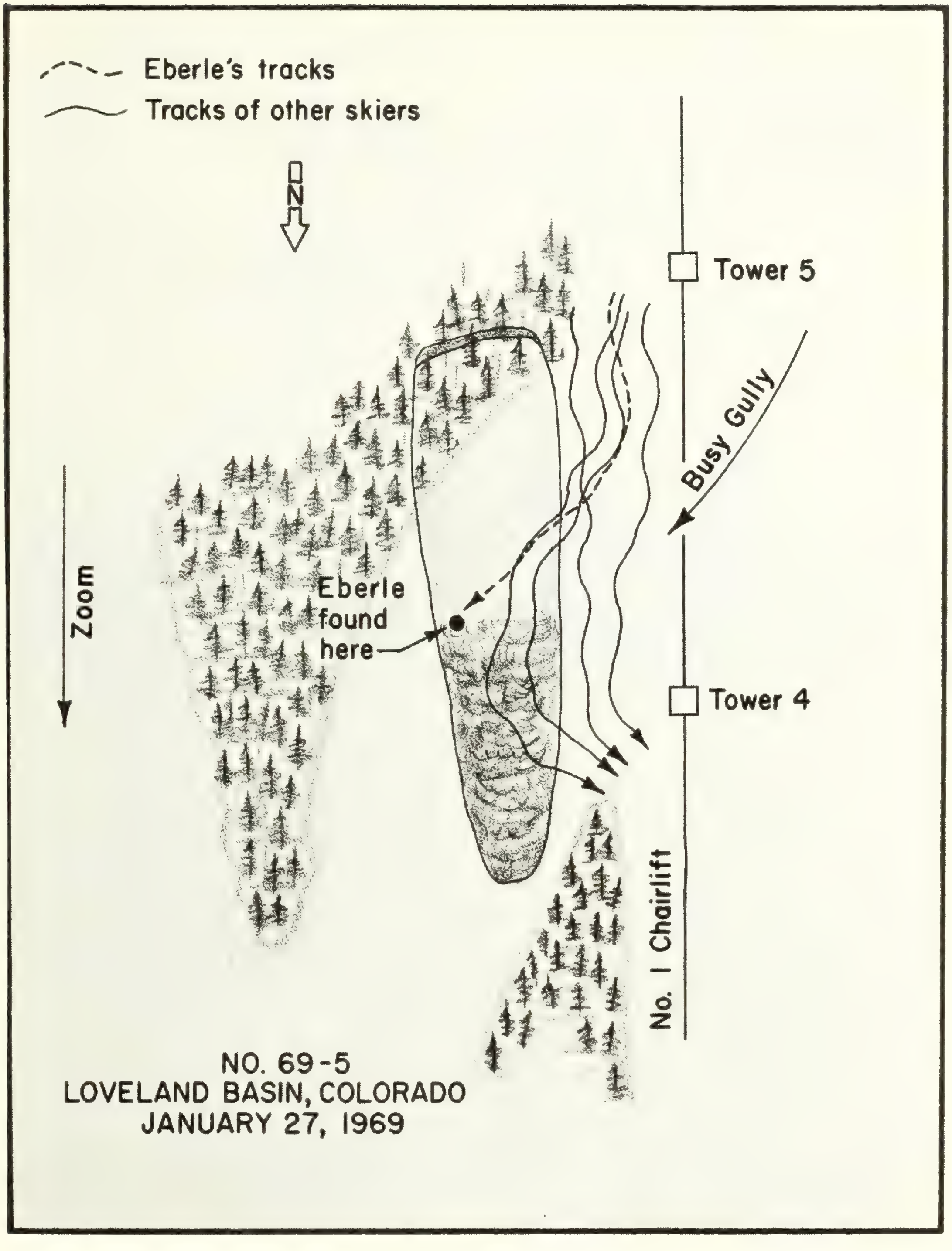
Probing was begun using ski poles and skis, but within minutes, probe poles from the rescue cache were dropped off the chair. A coarse probe line was set up, and at 1020 one of the probers struck Eberle's body. She was hurriedly dug unconscious from beneath 4 feet of snow; mouth-to-mouth resuscitation was begun immediately. Oxygen, which had been dropped off the chair, was also administered. The victim very shortly began breathing more easily and regained consciousness. She was then put in a toboggan and taken to the patrol room for further treatment. She made a quick recovery.

To make sure there were no more victims buried in the slide, a second probe line was started. After covering the debris with negative results, rescue operations were concluded.

Avalanche Data

This avalanche was a small soft slab approximately 200 feet long and 50 feet wide. It occurred on a north-facing slope with no record of previous avalanches. The fracture line occurred in a medium stand of spruce and subalpine fir above the Busy Gully ski run.

It cannot be determined whether this slide released naturally or was triggered by the skiers. There is a tendency to feel that the slide was artificially released. However, during the period from 0800 to 1300 on the 27th, five of the Seven Sisters immediately to the east and three areas on the headwall just above the ski area released naturally.



NO. 69-5
LOVELAND BASIN, COLORADO
JANUARY 27, 1969

Comments

This accident occurred on the second day of an extensive avalanche cycle in the Front Range. Protective skiing was carried out within the ski area, but no explosives were used. In view of the weather conditions and the amount of new snow, some hand charging was warranted. (After the accident, nine hand charges were thrown and released one avalanche.)

The accident area had been test skied (the standard procedure) shortly before the accident, and the slope had been opened. Nevertheless, it is important for skiers to realize that the best avalanche control methods are not 100% foolproof, as shown by this accident. Fortunately, a quick rescue prevented a fatality.

3 houses damaged

Weather Conditions

Weather records from the top of Vail Ski Area, 6 miles north of Redcliff, showed that 51 inches of snow fell from January 23 to 29. Temperatures during this period ranged from 9° to 28°F. Winds from the west and southwest prevailed.

Accident Summary

Ufracio Medina, his wife, and eight children had gone to bed early on the night of January 29. Snow continued to fall, and the temperature was near zero. At about 2130, the snow on the mountainside behind Medina's small frame house broke away and slid down the slope. The snow poured through the back door, around the house, and over the roof.

Minutes after the slide, the town marshall rushed to the house which was now buried under 10 feet of snow. When he arrived, he awakened the entire family that had incredibly slept through the whole episode! The house had held together, and no one had been injured.

A tunnel was shoveled out to the front door and the family evacuated. Two other houses were hit, but no injuries resulted.

Comments

Few details are available on this accident. The type of avalanche, the steepness of the slope, and the length of the slide are not known, but the slide must have been coming to rest when it struck the house. A fast moving avalanche would have demolished the frame house. As it happened, the snow knocked in the back door and poured into an unoccupied room. This lucky family had a very close call!

No. 69-7 Omak, Washington January 30, 1969

2 caught, 1 buried

Accident Summary

On the morning of January 30, 17-year-old Greg Hendrick and two friends, Dan and Steve Minnich, went to a steep-walled canyon near their homes to play on and dig tunnels in the snowdrifts there. After digging in the snow, the boys then decided to slide down the steep slope on their backs. It was about 1130 when Greg slid about halfway down the 100-foot incline and waited there in the snow, watching Steve zoom toward him.

Steve had stopped and stood up just uphill of Greg when a 150-foot-wide slab of snow broke loose from the slope above them. Before the two boys had a chance to move, the clubbing impact of the avalanche hit them and sent them hurtling toward the canyon's narrow bottom. Racing spread-eagled down the slope, Greg struggled helplessly as what he thought was just a small snowslide sped him toward the opposite wall of the canyon which angled up in a sharp "V". He slammed against the opposite wall, the snow surging up the bank and settling over him and the canyon bottom.

Meanwhile, Steve was having the ride of his life. He had landed on a large slab of snow which he rode to the bottom. Looking directly down on his friend, Steve watched as Greg disappeared beneath the snow. When the slide stopped, Steve remained on top and could see no sign of his friend.

Rescue

Steve dug frantically in the snow at the spot where he had last seen Greg. Realizing that his efforts were gaining little, he scrambled to the crest of the hill where his brother Dan, because of a strong wind blowing, had not heard the avalanche and was unaware of the accident. The brothers grabbed the shovels that had been used in their tunnel digging and ran down the canyon's slope.

Under the snow, Greg was unaware even of which direction was up. Completely weighted down by the snow, the only movement he could make was to wiggle a few fingers. At first he thought he may have been covered by only a few inches of snow. He quickly realized, however, that he must be much deeper: his lungs screamed for air as the pressing snow allowed no room for chest expansion.

From somewhere he heard the muffled voice and footsteps of Steve. He shouted hoping the noise would give Steve an idea of his location. His efforts went unheard, and his hopes dimmed when the sound of footsteps faded as Steve went back up the hill to get his brother.

Shortly before 1130 at the Hendrick home, his mother suggested to her husband that he go check on the boys. Not accustomed to checking up on them like that, Howard Hendrick at first demurred but finally consented. He began walking toward the canyon and at one time thought about returning home for a better pair of boots. He arrived at the canyon's brink about 2 minutes after the avalanche. He saw what had happened, scrambled down the hillside, took a shovel, and began digging hard. Steve's first digging attempts with his hands had marked the spot where Greg was last seen, and this seemed the best place to start digging.

Underneath the snow, Greg had given up his yelling to save the little energy he had left. He had given up any hope of being found alive and began wondering how long it would be before his body would be found. A pounding headache and acute shortness of breath were his only physical pains; then a gentle numbness began to settle over him.

Suddenly his father's shovel struck him on the right cheekbone! He instantly sensed the fresh air and was able to breathe again. It took another 15 minutes to clear the rest of the snow from him and pull him free. He had been buried on his back in a contorted position under 4½ feet of snow. He had been buried only about 6 minutes, but to Greg it seemed much longer.

Comments

Except for a series of fortunate coincidences, Greg would have died in this small soft-slab avalanche. First, Steve was able to mark almost the exact spot of burial; second, the shovels were right on the spot; and finally, Howard Hendrick arrived on the scene almost immediately. Greg concluded that the worst part of the nightmare was the utter helplessness he experienced. The snow was so heavy on top of him that he could do nothing to help himself: he could only wait to be rescued or to die. Good luck was on his side.

While buried beneath the snow, Greg was able to hear Steve's voice and footsteps, yet his own shouts for help went unheard. This one-way phenomenon of the propagation of sound waves through a snowpack is well-documented by numerous avalanche victims but is not well understood and deserves investigation. In one case, not even four revolver shots fired by a man buried in an avalanche were heard by the rescuers!

1 caught, buried, and injured; 1 house destroyed

Weather Conditions

During the last 3 weeks of January 1969, the temperature in the Pinehurst area of northern Idaho had never reached above the freezing point. Snow had fallen almost daily during this period, and strong winds had been blowing. About 2 feet of new snow fell on January 30 and 31. Snow continued to fall on February 1, and on the 2nd, rain began falling with the snow as a warming trend began. Precipitation had stopped by February 3.

Accident Summary

The home of Mr. and Mrs. Richard Buckham, an elderly couple in their seventies, was located about a mile up Pine Creek from Pinehurst. The one-year-old house was one of about half a dozen located on the flat and at the toe of a steep slope. The Buckham's house sat at the mouth of a small draw in the hillside.

At about 0830 on February 3, the snow fractured just below the ridge and descended the narrow draw which was sparsely covered with brush and trees. The avalanche struck the Buckham's house with great force, cutting it in half. Part of the house was knocked 40 feet off its foundation and demolished; a side bedroom was left standing.

Mr. and Mrs. Buckham were in the house when the avalanche struck. Mr. Buckham was in the bedroom that remained standing and was unhurt; Mrs. Buckham was in the other part of the house and was buried under the broken walls and boards which were covered by about 3 feet of avalanche snow.

Rescue

Neighbors heard the slide as it hit the house and acted immediately. The Pinehurst fire hall was telephoned, and the call was relayed to the Kellogg Fire Department. The Kellogg firemen arrived at the scene at 0855 and organized the rescuers who were already there.

Snow was shoveled from the wreckage, and pieces of the house were removed as they were uncovered. A trench was begun through the center of the debris, and at about 0930 one of the rescuers yelled that he saw something. Some gray could be seen, and the snow was quickly cleared away from Mrs. Buckham's face. She had snow in her mouth, and as soon as this was removed she exclaimed "Oh, my God!"

Mrs. Buckham had been found under 3 feet of snow, but two plywood doors had fallen on top of her forming an air space about 1 foot high. Her face was buried in the snow and her body was firmly pinned down. She said she could hear the rescuers digging and talking but could not yell because her mouth was filled with snow. She had never lost consciousness but was suffering from shock and a badly fractured left leg. A chain saw was needed to cut the timbers pinning her legs down. She was then rushed by ambulance to the Kellogg hospital for treatment.

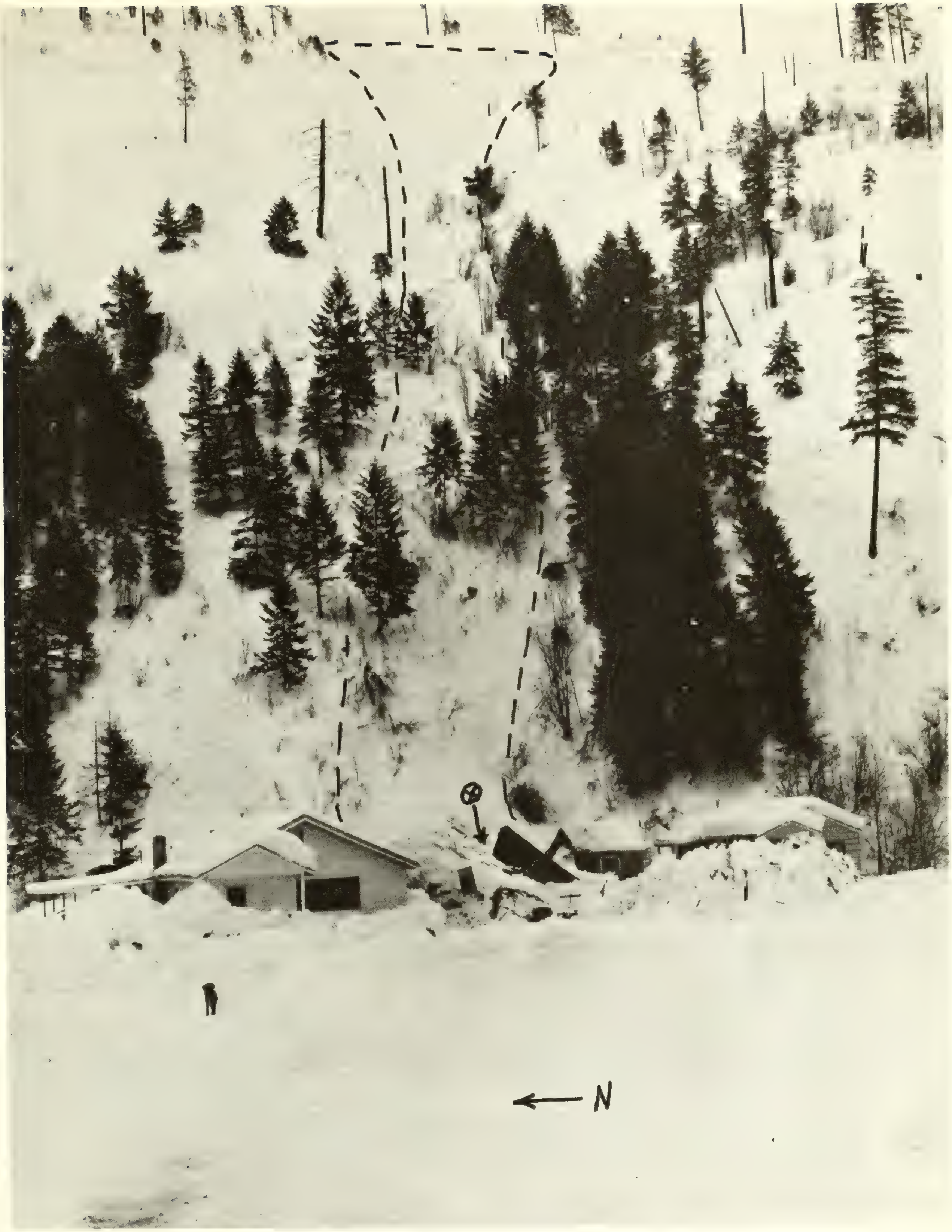
Avalanche Data

This was a natural soft-slab avalanche that released in a small bowl in the lee of the ridge. A small cornice had built on the ridge line. The slide was confined to the draw and was about 50 feet wide when it emerged at the bottom. It traveled an estimated 300 feet down the slope. The houses on both sides of the Buckham's narrowly escaped the slide.

This avalanche path has a slope angle of about 33°. The starting zone is mostly free of tree cover, but several trees and bushes grow in the track. Even though this avalanche had sufficient force to destroy a house, none of the trees in the path were taken out because of their small cross-sectional area.

Comments

This house survived only 1 year after being built in the runout zone of an avalanche. Some houses last longer; some, not so long. None, however, would have been built if avalanche zoning laws had been in effect.



No. 69-8. Pinehurst, Idaho. The wreckage of the Buckham house between two neighbors' houses which were undamaged. The location of the victim is marked. The entire avalanche path is visible behind the wreckage.

3 caught and partly buried

Weather Conditions

On February 8 to 10, 30 inches of snow fell at Paradise before turning to rain on the afternoon of the 10th. Late on the 11th, the rain turned back to snow, and intermittent snow fell through the 13th. On the morning of the 14th, the wind was calm, and the temperature was 26°F. The recent snowfall brought the depth of snow on the ground at Paradise to 250 inches.

Accident Summary

Three park rangers—Pete Hart, Lee Henkle, and Roy Sanborn—left the Paradise Ranger Station on the morning of February 14 and climbed toward Camp Muir which is perched at the 10,000-foot level on Mount Rainier. They were traveling on snowshoes and were taking the summer trail route. They began ascending the very steep slope beneath Panorama Point, crossing at an area of least avalanche hazard because of the short slope and flat runout.

At 0905 the party was traversing up the slope and had come about 60 feet up from the base when the snow fractured on a wide front 50 feet above them. All three were hit by the avalanche and swept to the bottom of the slope. Each man was buried to the chest and was able to dig himself out. No injuries resulted.

Avalanche Data

This avalanche was a SS-AO-3 triggered by three men on snowshoes. The fracture line varied from 1 to 3 feet deep and was 200 feet wide; the slide fell a vertical distance of approximately 100 feet. The sliding surface was a ¼-inch-thick ice layer.

This slope, lying at the 6400-foot elevation on the south side of Mount Rainier, has a southwest exposure and is a known avalanche path. It has a steepness of 42° to 50° and is open except for a few patches of alpine fir along the top.

Comments

All three rangers were experienced mountaineers and had training in avalanche forecasting and control. Their assessment of the accident was that they had underestimated the sliding potential of this slope; it had been climbed many times before without incident and it did not appear dangerous at first inspection. Of the possible routes to Camp Muir, this one was the least hazardous because of the short exposure to risk. In retrospect, the group should have (1) removed their snowshoes and walked directly up the slope, (2) exposed only one man to the hazard at a time, and (3) used their avalanche cords.

5 caught, 2 injured

Accident Summary

On the morning of February 21, avalanche control was carried out with the lower 75-mm recoilless rifle before Mt. Alyeska Ski Area was opened. This resulted in three size 4 avalanches and one size 5. At the end of the ski day, more control work was done from the upper gun above the chairlift. Snow Ranger Chuck O'Leary began firing at 1600. The first shell on Center Ridge caused no release. Convinced that the ridge should release, O'Leary aimed at another fracture zone on Center Ridge and brought down a large part of the ridge (SS-AA-3).

The next shot was fired at 1612 in the Palisades area above and behind Center Ridge. In the past when this area released, the avalanche ran behind Center Ridge stopping in a transition zone, or if large, ran down onto a second transition in the Silvertip area. When the 75-mm shell hit in the Upper Left Palisades, a fracture line shot across three other areas—Alyeska Chute, Sunspots, and Alyeska Peak—for a combined width of nearly a mile.

The avalanche that resulted traveled down the mountain at terrific speed. It overran the first transition behind Center Ridge and then zoomed across Silvertip, the second transition. Here it turned and dropped down and across the Main Bowl trail and into the Canyon. The dust cloud that developed was 400 to 500 feet high.

When the avalanche dropped into the Canyon, the effects of either a devastating air blast or an air-borne powder avalanche were seen. Although the canyon wall on the Racing Trail side is over 200 feet high, the powder avalanche tore out 100 trees from 8 to 20 feet tall that screened the trail from the Canyon. Skiing down the Racing Trail at this time were four patrolmen on sweep and one recreational skier. The airblast struck them, knocking them off their skis and rolling and tumbling them about 50 feet. One patrolman suffered a cut nose and another a sprained knee.

The avalanche continued down the Canyon and spilled out onto the Racing Trail leaving 3 feet of debris on the trail. The slide came to a stop 500 feet short of the base area, but the dust cloud completely covered and a strong wind buffeted the base area, sending relaxing skiers running for cover.

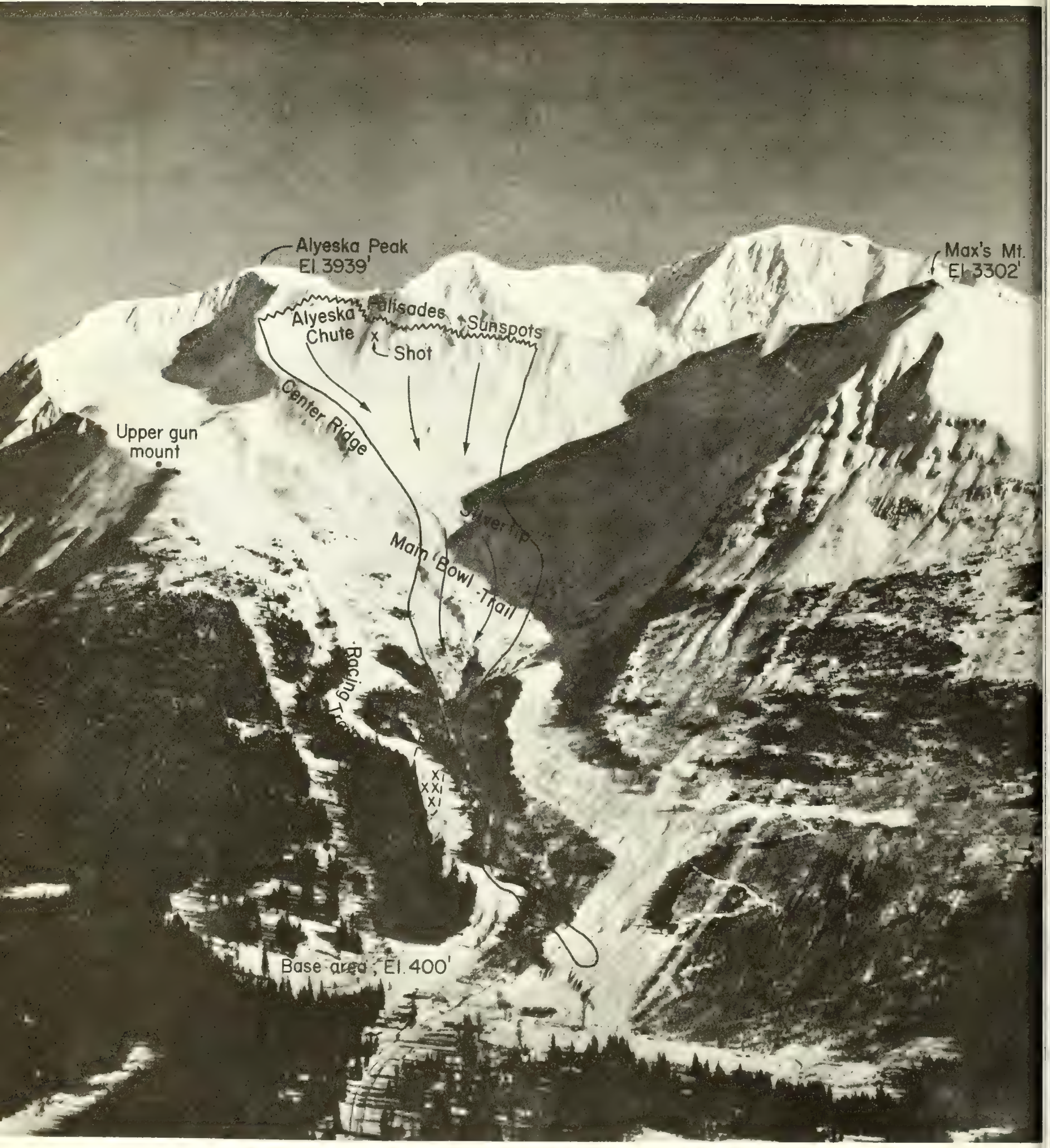
Avalanche Data

This frightening avalanche was classified as SS-AA-5-G-J; the G indicates that the avalanche ran to the ground in the starting zone and the J indicates airblast. The fracture line averaged 4 feet in depth and was a mile long. The avalanche had a vertical drop of 3400 feet and traveled a distance of 2¼ miles.

Comments

This was the first time that an artificially released avalanche in the upper area had overrun the transitions and reached the lower ski area. A complete revision of safety procedures was begun following this avalanche. Snow Ranger O'Leary said this was the largest and most violent avalanche that he had ever witnessed at the ski area. Even the two large avalanches released during the 1964 Good Friday Earthquake were dwarfed by comparison.

The destructive airblast that accompanied this avalanche occurs only with very large avalanches and can reach amazingly forceful proportions. In a documented case near Berthoud Pass, Colorado in 1964, a 7000-pound dump truck and two heavy attachments for a tractor were carried 65 feet horizontally and 50 feet downhill by what was assumed to be the airblast from a fast-moving avalanche. Amazingly, the truck landed on its wheels and not so much as a window had been broken!



No. 69-10. Mt. Alyeska, Alaska.

No. 69-11 Mineral King, California February 24, 1969

2 caught, 1 killed; 2 cabins damaged

Weather Conditions

In anticipation of developing Mineral King into a major ski area, several residents were staying at the area through the winter. Weather records were being kept, but these were lost in the avalanche accident. The winter of 1968-69 was, however, a severe one with very heavy snowfalls. A storm raged over the weekend of February 22 and 23 with 5 feet of new snow being reported on the 22nd, bringing the total snow depth to 17 feet.

Accident Summary

On February 17, two Forest Service employees arrived at Mineral King for avalanche control with the 75-mm recoilless rifle. Empire Mt. and Juniper Ridge were shot with no avalanche releases. The residents expressed concern about snow depths, loads on roofs, and the diminishing supply of propane and fuel. On February 21, two residents left Mineral King under orders from the Walt Disney project manager. Two men, Wally Ballenger and Randy Kletka, remained at Mineral King. A Disney employee, Ballenger wanted to finish the monthly weather report; Kletka, not employed by Disney, decided to stay also. For safety, the two men decided to stay in separate cabins.

At 1800 on February 24, an avalanche just missed the cabin in which Kletka was staying, although some snow had hit the cabin without damage. Kletka radioed the Forest Dispatcher and asked that arrangements be made to evacuate both men the next day or as soon as possible.

A few minutes later, Ballenger was talking to Kletka on the intercabin telephone when a large avalanche came down, crushing the side of Ballenger's cabin and cutting the telephone line. Ballenger dug an air hole from the back door upward about 8 feet to the surface and then retired for the night. He had no further communication with Kletka and did not know that another avalanche had struck Kletka's cabin, caving in the west end and trapping him inside.

Rescue

At 0800 on the 25th, the Forest Service tried to contact Mineral King by radio and got no answer. In the early afternoon, an airplane was sent to view the area, but bad weather prevented the pilot from seeing the ground. The pilot did, however, make radio contact with Ballenger, who said he was all right and could get out of his cabin but he had no knowledge of Kletka's situation. Rescue plans were made for the following morning.

The rescuers assembled at Three Rivers, and the first group was flown in by helicopter shortly after 0900. Two rescuers were deposited near Ballinger's cabin where they could see a pair of skis and a red flag stuck in the snow. They walked to this marker, found the tunnel leading down into the cabin, and found Ballenger safe inside.

They then walked to the general location of the cabin occupied by Kletka. The snow surface was mostly level and undisturbed, and the rescuers had great difficulty in even finding the cabin. A natural hole in the snow revealed the roof of the village store, and from this they were able to estimate the location of Kletka's cabin.

More rescuers arrived by helicopter, and they helped dig and probe for the cabin. At 1130 they hit the roof of the cabin under 12 feet of snow. The spot was above the bathroom, and they chopped through the roof. The bathroom was free of snow, but the adjacent bedroom was caved in so they were unable to reach the rest of the cabin. When they chopped through the roof there was evidence of a fire and the strong odor of smoke in the cabin.

More rescuers arrived by helicopter and helped dig a second hole 14 feet deep before hitting the living room roof. The living room was caved in, and there was evidence of fire. They moved over slightly and chopped through the roof over the kitchen, which was free of snow. The rescuers dropped through this hole into the kitchen at 1415. There they found Kletka's body by the open kitchen door; he had died of asphyxiation. Several cats and dogs in the cabin had also died of asphyxiation.

As the rescuers reconstructed events, Kletka had started to dig out from the kitchen door but was overcome by smoke. The fire had not been intense but had consumed much of the oxygen in the buried cabin. The fire started from a pot-belly stove in a corner of the living room. Kletka could not have reached the fire from the kitchen because of the debris from the collapsed living room roof.

The rescuers could only guess at what had happened, but there was evidence that Kletka had packed a knapsack before starting to dig, apparently not recognizing the danger of asphyxiation. Had he started digging out immediately, he might have made it. He had a snow shovel and a flashlight and had plenty of room in the cabin to shovel snow into as he tunneled. However, he had dug only a few feet before being overcome.

Comments

There is no previous record of such snow depths in Mineral King nor of avalanches running as far as the store and cabin areas. This accident provides ample evidence that cabins built in the runout of avalanches may be safe in normal winters but are decidedly unsafe in heavy-snowfall winters. In this case, the valley was narrow, and the rescuers were not even certain from which side of the valley the killer avalanche came. This cabin was threatened from two directions!

The only defense against such extreme conditions is immediate evacuation. The men should have left the area on their own following the first close call.

No. 69-12 Kyle Canyon, Nevada February 25, 1969

3 caught; 2 buried and killed; 1 house destroyed; 1 water tank destroyed

Weather Conditions

Record snows had fallen in the mountains west of Las Vegas. (This was the same storm that dumped heavy snow on Mineral King in No. 69-11.) In places, snow depths were 643% above average on February 25. Around 11,919-foot Mt. Charleston, 50 inches of new snow had fallen on top of the existing snowpack. The temperature was in the twenties and light winds were blowing. On the morning of the 25th, the Clark County Sheriff's Office closed the Kyle Canyon road to all persons except homeowners. Snowplows were unable to cope with the record snow; roads were impassable.

Accident Summary

Homeowners in Kyle Canyon reported that many roofs were starting to sag and began requesting help. At 1000 on February 25, evacuation operations began with the rangers and sheriff personnel hauling people from the subdivision by weasel and on foot. The Kyle Canyon Fire Station was used as a base for the operation. At 1600, Mrs. Pierczynski called in saying she was quite nervous and wanted assistance in leaving home. She was at home with her 9-year-old son and 11-month-old baby. Rescuers immediately started for her home in a weasel, but the vehicle became buried in the snow, forcing them to turn back.

At 1730 a report came in to the fire station that an avalanche had run across the highway a quarter of a mile above the station. A fireman, a sheriff's deputy, and Mr. Pierczynski, who was returning from work and had just arrived at the station, left the fire station on foot to check on the slide and on Mr. Pierczynski's house. When they reached the slide area, they saw that it had squarely hit the Pierczynski house. The two-story house had been knocked completely off its basement foundation and broken into several sections which were carried 150 feet down the avalanche path.

The three men climbed up from the road and began looking through the wreckage for signs of the three occupants. The baby's crib was found on top of the wreckage under a sheet of plywood. Miraculously, they found the baby still in the crib, wrapped in a blanket, and sound asleep! However, a further search revealed no trace of the mother and the 9-year-old boy.

Rescue

The deputy returned to the fire station with the baby and called the Sheriff's Search and Rescue Squad; this unit then assumed command of the rescue effort. Later that night, the National Ski Patrol was called, and at 2200, six patrolmen from nearby Lee Canyon Ski Area began probing the debris. By 0200 the next morning, the area from the house to the toe of the debris had been probed but no clues were found. The work was slow and tiresome as many uncertain objects were felt by the probers and these had to be checked out by digging down through 10 feet of wet snow.

At dawn on the 26th, a D-8 cat arrived and began removing debris.At 0815 one of the family's dogs was found alive under a portion of the roof. At 1415 a second dog was found crushed in the wreckage. A few minutes later the bodies of Mrs. Pierczynski and her son were found; both had been crushed to death by heavy house beams.

Avalanche Data

This large avalanche was a natural soft slab that released just below a vertical cliff at the 8000-foot elevation on the south side of Mt. Charleston. The slide was about ¾ mile long and ran down a slope that was brush covered but had been stripped of timber in a fire about 15 years before. There is no record of this slope sliding in the last 30 years.

A contributing factor in the complete destruction of this house was a water tank located 200 yards behind and above the house. This tank contained 100,000 gallons of water and was hit by the avalanche. This explains the wet snow found by the rescuers.

There were about 20 other slides in the Mt. Charleston area within a 24-hour period. Considerable damage was done to two Forest Service campgrounds, and two other unoccupied homes were destroyed. A total of 26 house roofs collapsed under the snow load.

Comments

This was a rare storm that brought heavy snows to southern Nevada, and the avalanche paths responded. Although this slope had not avalanched for at least 30 years, when it did run it was deadly.

People who insist on building houses in hazardous areas, whether they are aware of the hazard or not, must be willing to evacuate their homes during periods of heavy snowfall. Two homeowners evacuated in time; for Mrs. Pierczynski and her son, evacuation efforts came too late.

This was the fifth accident in less than a month involving homes built in avalanche paths (see also Nos. 69-2. 69-6, 69-8 and 69-11); two resulted in fatalities. As the reader shall see, this volume contains several more such accidents, most of which could have been prevented by zoning restrictions.

1 caught and buried

Weather Conditions

About 18 inches of snow had recently fallen at Bear Valley. By early afternoon on March 1, the sun was shining brightly, and the temperature was in the thirties.

Accident Summary

At about 1300 on March 1, the lower lift at Bear Valley was opened. Bill Heyenbruch was skiing the powder alone on the runs served by this chair and had already released a small soft slab but was not caught in it. He then released a second small avalanche on a short slope and fell. The flowing snow quickly engulfed him, and he found himself gasping for air. His skis did not release and it felt as though they were dragging him under. He began swimming motions with his arms, but the slide slowed to a stop before the swimming had much effect.

Heyenbruch was completely buried, lying on his back. The layer of snow was thin, and he was able to sit up and clear snow from his face. It took another several minutes to dig himself out and locate his poles. He was uninjured but was out of breath and very cold. He continued to ski and had one more slide release beneath his skis.

Avalanche Data

The avalanche that caught Heyenbruch and the other two he released were all classified as SS-AS-1. Fracture lines varied from 1 to 1½ feet deep, and none of the slides ran much more than 50 feet. At least one other slide was released by another skier that afternoon.

Comments

A minimum of information is available for this accident. However, no fewer than four small soft-slab avalanches were released by skiers this day; thus, it is evident that snow conditions were unstable. The victim violated a cardinal rule by skiing alone; he was fortunate to have been only lightly buried.

2 caught; 1 partly buried and injured

Weather Conditions

Until March 4, almost no snow had fallen at Alpental since February 13 when a sizable storm came to an end. Light snow began to fall on the morning of March 4 and intensified during the day. By the morning of the 5th, 14 inches of new snow containing 1.42 inches of water equivalent had fallen at the study plot at the base area; 18 inches of new snow covered the upper mountain. The snow fell on a firm crust which had formed and persisted during the previous 2 weeks. Southwest winds of 10 to 20 m.p.h. blew while the storm was in progress.

Accident Data

Shortly after 0800 on March 5, pro patrolmen Doug Rouraback and John Kubiack left the top of Chair 2 at the summit of Alpental to run their avalanche route. The area's avalauncher was temporarily buried in a snowdrift, forcing the patrol to hand charge several chutes of the International area from above. To reach the top of International chute 1, it is necessary to traverse around the summit of Denny Mt., the highest point in the ski area. This traverse takes the control team across an open face on the southeast flank of Denny Mt. This face is normally shot with a 75-mm recoilless rifle; however, on this day the face was closed to skiing because of bad weather and small crowds. Hence, no gun control was effected.

The two patrolmen left the chairlift and began a climb directly up the ridge toward Denny Mt. Rouraback skied over to the edge and hand-charged chute 3 of International, while Kubiack started across the open, southeast-facing slope toward the opposite (west) ridge. On his traverse, Kubiack triggered a small soft-slab avalanche that released above him and carried him 75 feet to the flat below; he was buried to the waist. He was able to dig himself out and climbed back up to join Rouraback.

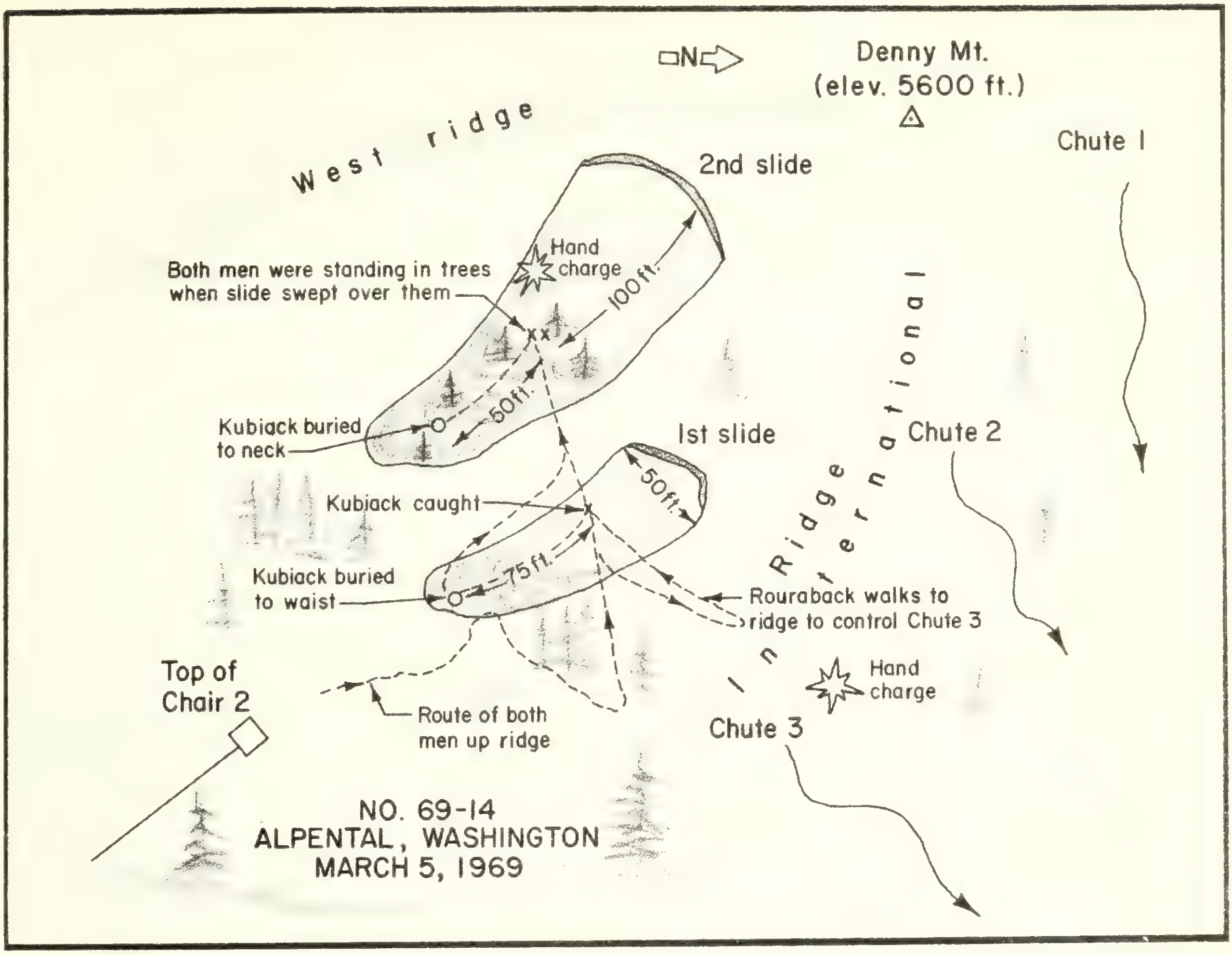
The two men continued their traverse but came to a stop beside a small group of trees. Before attaining the west ridge, they had to cross a heavily loaded slope in the lee of the ridge. Kubiack threw a charge onto this slope, and both men anchored themselves against the trees.

The charge released a shallow soft-slab avalanche which fractured 100 feet above the shot point and above the two patrolmen. The avalanche flowed down over both men; Rouraback managed to hold tight, but Kubiack was unable to hold his position and was swept downhill. When Rouraback was able to see again, Kubiack was nowhere in sight. Rouraback skied down and found his partner's hat on top of the snow. A few minutes later he found Kubiack mostly buried in a small island of trees. Kubiack had been carried 50 feet and was lying on his side with only his head sticking out of the snow. One ski binding had been broken when he hit the trees, and he complained of chest pains, later diagnosed as torn cartilage. He was able to make it back to the top of Chair 2 under his own power where he caught a ride to the base area. Rouraback completed the avalanche route without further incident.

Avalanche Data

The first slide that caught Kubiack was classified as SS-AS-1. It fractured 1 foot deep and 50 feet across and ran a little more than 100 feet slope distance. The second avalanche was a SS-AE-2, fracturing only 6 inches deep but across a broad front. It ran about 200 feet down the slope. Both slides occurred on the open slope on the southeast side of Denny Mt. above the top terminal of Chair 2. The slope is very steep in the starting zone—45° or steeper—and slides frequently. It especially reacts to either heavy snows or west or southwest winds.

March 5 was a high-hazard day at Alpental: almost every path that was shot ran. All three of the International chutes ran, with fracture lines averaging 18 inches in depth and falling as much as 900 feet vertically. This instability was within the new snow layer, with the hard crust providing a good bed surface.



Comments

This accident was caused by not heeding the warning signs that indicated a very touchy situation. Many avalanches were running in the area, and Kubiack had already triggered and been caught in one small slide. After the hand charge was thrown, the two patrolmen should have retreated to a point of greater safety.

The route across this slope is a dangerous one. The steepness and lack of cover make traversing, and even hand charging, this slope very risky business. It should be crossed only after being shot with the 75-mm rifle.

1 caught, buried, and killed

Weather Conditions

Light snow fell at Paradise, Mount Rainier from March 3 to 8 with a total accumulation of 29 inches, bringing the total depth at Paradise Ranger Station to 250 inches. On the night of March 8, a strong east wind began blowing. Windspeed varied from 40 to 70 m.p.h., and west-facing slopes were heavily loaded by wind-blown snow. The morning of March 9 broke clear, cold and windy.

Accident Summary

John Aigars, age 31, left Seattle at 0500 on the 9th for a ski tour to Camp Muir, located at the 10,000-foot level on the south side of Mt. Rainier. He parked his car in the Paradise parking lot and began his climb alone, not bothering to sign the register. At about 1030, he reached the bottom of Panorama Point and began ascending the slope with climbing skins on his skis. This was a steep southwest-facing slope that was heavily loaded with wind-deposited snow. (This was adjacent to the avalanche slope in No. 69-9.)

Apparently while he was near the middle of the slope, the snow fractured above him. The avalanche knocked Aigars down, carried him to the bottom of the slope, and completely buried him.

Rescue

At 1800, Aigars' car was the only one left in the Paradise parking lot. The park ranger checked the sign-out register and found no unaccounted-for parties. When the car was still there at 2000, the license number was checked through the state patrol to find the owner's name. Aigars' parents were soon located. They told the park ranger that their son had planned a one-day trip to Camp Muir and still had not returned; he was long overdue.

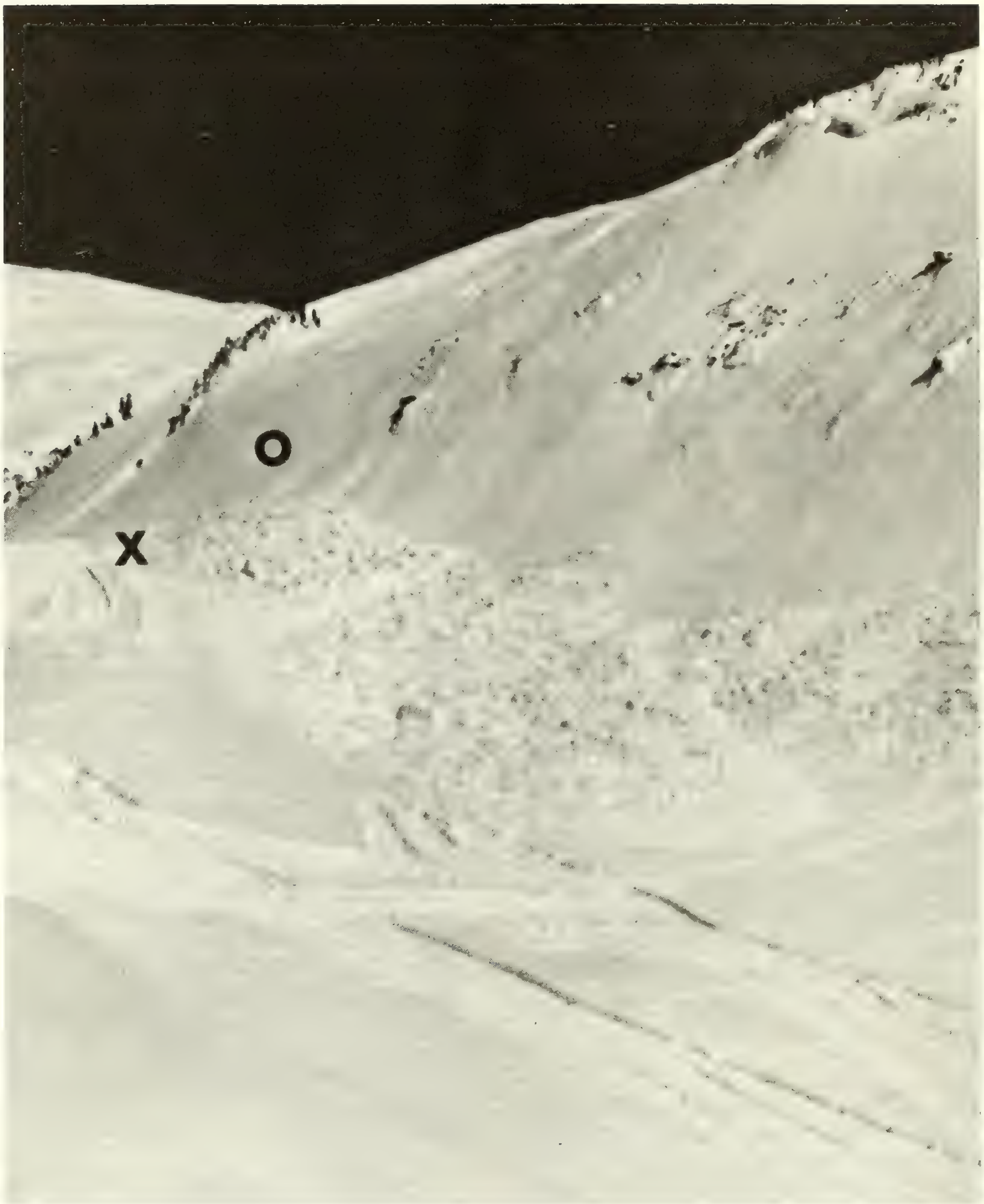
At 2200, two park rangers boarded a snow cat and drove to the base of Panorama Point to check an avalanche that had been reported earlier in the day. The weather was still clear and cold, but 50 to 70 m.p.h. winds were causing heavy blowing snow. The avalanche debris was checked, revealing no clues. Because of the poor visibility and high avalanche danger, it was decided to delay further rescue attempts until daylight.

At 0700 on March 10, an aerial reconnaissance flight was begun to cover the Muir Snowfield and adjacent areas. The flight detected no sign of the missing skier. By midmorning, ground crews were organized, and at noon four rangers were flown to Camp Muir by Air Force helicopter. They worked their way down the Muir Snowfield checking for signs or tracks. Two other rangers arrived by snow cat, but no clues were found by the six searchers.

Earlier in the afternoon, four rangers went to the avalanche area below Panorama Point, searching the debris and checking the perimeter of the slide for tracks. Again, no clues were found. At 1900, four German Shepherd avalanche dogs were brought to the avalanche site. These were from the German Shepherd Search and Rescue Dog Association in Seattle. They worked the area for 3 hours but to no avail.

On the morning of the 11th, another flight was initiated to expand the search area, because of recent information that the missing skier frequently left his planned routes. In addition, three search dogs were again taken to the Panorama Point avalanche site. Two other dogs began working up the east side of the Nisqually Glacier from Glacier Bridge to check avalanche debris in that area. Plans were also made to bring in about 35 probers around noon.

At 1030, one of the avalanche dogs working the Panorama Point avalanche found the body of John Aigars. He was found facing uphill and buried at an angle with his head about 2 feet under the surface and his feet about 5 feet under. The snow was so tightly packed around his body that he had obviously been unable to move at all. There was no ice mask around his nose and mouth, indicating that suffocation was probably very rapid after burial. His pack, poles and skis were still attached to his body, and climbing skins were on



No. 69-15. *Panorama Point, Mt. Rainier, Washington. View of the Panorama Point avalanche showing the victim's probable location when caught (0) and location where the body was found (X). This photograph was taken 2 days after the accident; most of the fracture line at the top of the slope has filled in with wind-blown snow. National Park Service Photo.*

his skis, indicating that he most likely triggered the slide while ascending the slope.

Avalanche Data

This was a medium to large avalanche on a wide and fairly short slope. It was classified as SS-AS-3 or SS-AS-4. The slide was about 200 feet long and 400 yards wide. All but a short section of the fracture line had been filled with wind-blown snow when it was observed; this section of the fracture line was estimated at 6 to 8 feet deep.

This slope has a steepness of about 45° and had been heavily loaded in the starting zone with wind-deposited snow. The slope faces southwest and was therefore in the lee of the strong east wind that was blowing. The instability of the slab was shown by the great length of the fracture line.

Comments

The victim violated two basic rules of ski touring by traveling alone and by not signing out at the Ranger Station. A companion—if he, too, were not buried in the avalanche—would have given Aigars a chance of survival: the companion could have either effected a rescue or summoned help. By signing the register, Aigars would have at least notified the rangers that he was still on the mountain. As a result of this accident and the one on February 14, 1969 (No. 69-9), a blackboard showing current weather and avalanche conditions has been located over the sign-out register at the Paradise Ranger Station.

The rescue operation was very well planned and executed. The overall plan was first to exhaust all alternatives that could have resulted in finding the victim alive and only then to concentrate all efforts on the slides, where he would have certainly been found dead.

The value of avalanche dogs can readily be seen in this rescue. The avalanche debris covered an area approximately 100 by 400 yards. It would have taken 40 men about 8 hours to coarse-probe this area, an expenditure of 320 man-hours. However, several avalanche dogs were employed in 20- to 30-minute shifts and covered the area in about 4 hours. Had the snow been lighter and the victim not been buried so deeply, the dogs would have likely found him within 1 hour. The use of avalanche dogs in the early phases of an avalanche rescue is highly recommended.

4 caught, 1 killed; 2 vehicles damaged

Accident Summary

On Sunday, March 16, John Sellers, age 28, was driving along a logging road 3 miles off State Highway 20 and about 14 miles northeast of Missoula. With him were his wife, Beverly, and two friends, Mr. and Mrs. Charles Hutchins. At a spot where the road parallels the Blackfoot River, a small avalanche slipped down the mountainside above the road and partially buried the car. Only the wheels were buried, but the car was firmly stuck. As the four were attempting to free the car, a fisherman, Dee Cleveland, arrived in his pickup truck and offered his assistance.

Cleveland was unable to push Sellers' car out with his pickup. While the four stranded motorists made further attempts to dig out their car, Cleveland walked a short distance down the road to get some gravel to put under the tires. At this moment, the remaining snow cover broke loose from the mountainside above the unsuspecting victims. The avalanche roared down the slope and struck them and the two vehicles. All four victims, the car, and the pickup were hurled down a 20-foot embankment into the icy waters of the Blackfoot River.

Cleveland came running back up the road and hurried down the embankment. Beverly Sellers and both the Hutchinses were pulled from the river, but John Sellers had disappeared beneath the surface.

Rescue

Later in the day, a diver from Missoula entered the river and found Sellers' body in about 20 feet of water, a victim of drowning. The other three victims were hospitalized for treatment of minor injuries and observation.

Comments

There are numerous incidents of two or more avalanches on the same path over a short period of time. (Another tragic example of this is documented in No. 71-4.) When an avalanche releases below its normal release point, the snow slab above the fracture line is left hanging and undergoes a great increase in tensile stress, thus enhancing the likelihood of a second avalanche. This is a hazard that must be considered by all rescue groups. If the danger from a hanging snow slab seems imminent, control measures must be taken to minimize the risk to rescuers working below.

1 chairlift damaged

Weather Conditions

The weather during early April in the Mt. Alyeska region of Alaska had been very unsettled with intermittent rain and snow. Total new snow at the midway station (elevation 1,400 feet) at Mt. Alyeska Ski Area was 26 inches for the period from April 6 to 12. Temperatures at midway remained almost constant during the period, ranging from 30° to 33°F. Precipitation fell as rain from sea level to 500 feet, mixed rain and snow from 500 to 1,500 feet, and snow above 1,500 feet. Therefore, snow amounts were much higher in the starting zones of the avalanches that threatened the ski area than in the midway study plot. Wind action on the new snow was visible on the upper areas when the weather permitted observation. Snow conditions on the upper mountain were becoming increasingly more unstable, but poor visibility prevented the upper gun from being fired at these targets.

Accident Summary

On the morning of April 11, the lower 75-mm recoilless rifle was blind-fired at Max's Mountain because low clouds obscured the mountain. Eight rounds failed to release any snow. The upper gun again was not fired because it was not set up for blind firing. Rain and snow continued until the morning of Saturday, April 12, at which time the skies cleared.

On Saturday morning both the lodge and the ski patrol buildings were cleared of people before firing began. The lower gun released a large hard-slab avalanche on Max's Mountain. It ran fast and dry until it reached the heavy, wet snow at the 1,500-foot elevation; from there it continued as a wet-snow avalanche, digging to the ground. It moved very slowly near the end, finally grinding to a halt 300 feet above No. 3 rope tow.

At 0900, Snow Ranger Chuck O'Leary and his gun crew secured the lower gun and rode the chairlift to the upper 75-mm rifle. The first shot was on Center Ridge and released a large hard-slab avalanche which ran across the Main Bowl trail. Seven more rounds were fired into the Main Bowl area, releasing two more avalanches in the Shadows. It was now 1030, and the skiers were getting restless. It was decided that although the lift line and Racing Trail areas would be opened for skiing, the Bowl and the trails immediately below it would be kept closed. The Saddle and Shadows on the back side of Max's Mountain would be shot at the end of the day.

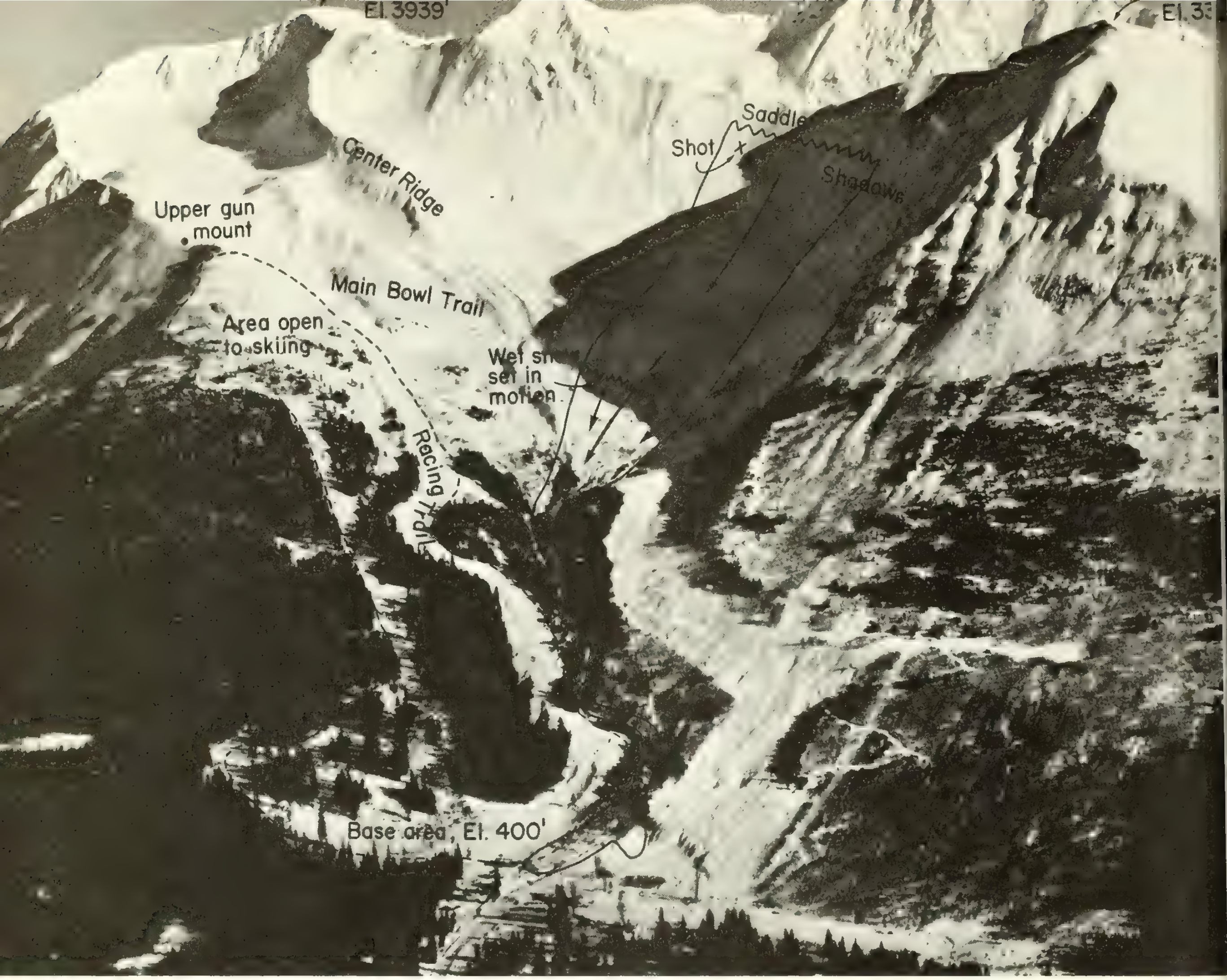
Hand charging and test skiing released only one small slide in the rest of the ski area. Many of the skiers fell down repeatedly trying to ski the heavy, wet snow but no problems developed. When the lifts closed at 1630, O'Leary and three others went to the upper gun and prepared for shooting. At 1710 when the all-clear was given by radio from the base area, firing began. Several rounds produced one small slide in the Shadows area.

The gun was then turned to the Saddle where the first two shots failed to release anything. The third shot was put into the upper left side. A large fracture line shot across the top of the Saddle for a distance of 600 feet, setting a major avalanche into motion. It moved very fast down the steep wall, throwing up an enormous dust cloud. The gun crew radioed to the bottom alerting them that a large avalanche had started.

As the avalanche moved across the lower part of Silvertip, the dust cloud began to diminish. The moving snow was now out of sight of the gun crew. The lower radio then called and stated that they had seen the dust cloud settle and everything appeared to be all right. The gun was then turned to the next target, and two more rounds were fired with negative results.

Then the lower radio crackled again saying they had just seen a tree go down in the Canyon. The next minute they excitedly said they saw an enormous mass of snow moving out of the Canyon. The upper gun crew secured the gun, strapped on skis, and headed for the bottom.

Meanwhile, a wall of snow about 25 feet high crept out of the Canyon toward the base terminal, moving more like a mudslide than an



No. 69-17. 1. Mt. Alyeska, Alaska.

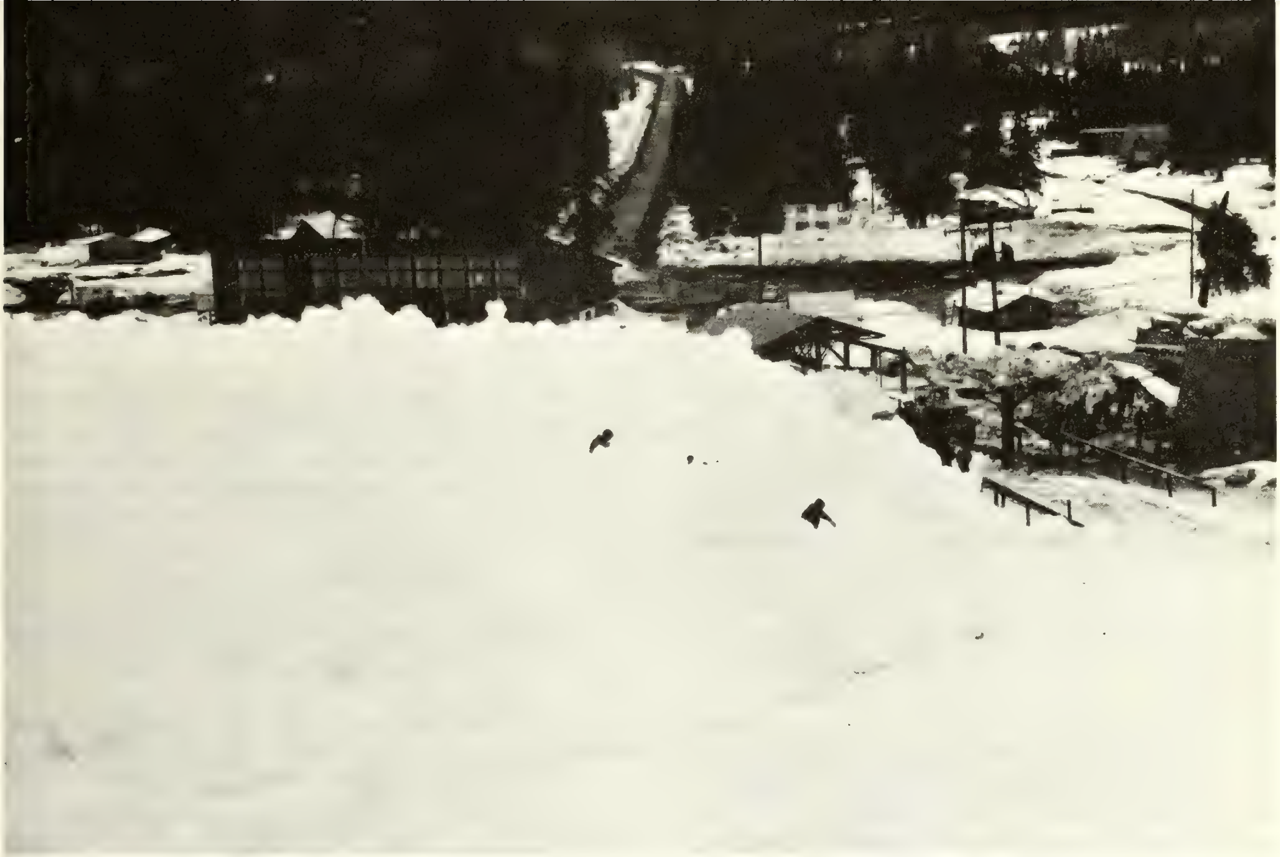
avalanche of snow! As the snow advanced, ski area personnel began moving everything that could be moved. A snow cat was hastily driven out of the path of the slowly advancing snow, and others began driving cars out of the parking lot.

The lower terminal of the chairlift was directly in the path of the avalanche. Dozens of people watched helplessly as the snow crushed the lift control building and slowly twisted and bent the steel support columns of the lift terminal. The avalanche then threatened the ticket office. The snow mass crept right to the building, pressed against walls and windows, and stopped without breaking a single pane of glass!

Avalanche Data

This avalanche was classified as HS-AA-5. It started at an elevation of 3,000 feet and stopped at the 400-foot level, a vertical drop of 2,600 feet. It had run a slope distance of more than 1½ miles. The fracture line was estimated at 600 feet in length and 2 to 6 feet in depth. The steepness of the starting zone was 35°.

Most avalanches releasing in the Saddle stop at the transition at Silvertip where the slope gentles to 10°. The unusual feature of this avalanche is that although it slowed and almost stopped when it hit the heavy, wet snow in the lower bowl area, it still had enough force to gouge out the wet snow and set it in motion. The wet snow then gained enough momentum when it dropped into the Canyon to carry it well past the Canyon mouth. The wet snow mass was about 25 feet high and 100 feet wide and moved so slowly that those rescuing



No. 69-17. 2. Mt. Alyeska, Alaska. The lower chairlift terminal sustained heavy damage from this avalanche. The mass of wet snow was approximately 25 feet deep.

equipment could keep ahead of the snow with a brisk walk.

Comments

This was the second avalanche of the 1968-69 winter that reached the base area from the Main Bowl (see No. 69-10 also). In the previous 10 years only one other avalanche had released from the Bowl and made it as far as even the Canyon. To Snow Ranger O'Leary, this pointed out the need for more constant control with the upper gun. This gun has now been setup for blind firing to prevent dangerous accumulations of new snow from loading the avalanche starting zones during prolonged periods of poor visibility.

An additional safety factor could be had by building a mound field on the transition directly above the Canyon. These cone-shaped mounds would act to dissipate the force of an avalanche and would retain more snow in this area, keeping it from dropping into the Canyon.

1 caught and injured

Weather Conditions

Six days of fine spring weather had reduced the snowpack at Alta from 104 to 84 inches by April 14. Snow began falling on the 14th, and by noon on the 15th, as much as 10 inches of new snow covered the upper mountain. Skies were cloudy on the 15th with fog, light snow, and poor visibility. Avalanche conditions were considered high for the Peruvian Gulch area, and this part of the mountain was closed to all skiing and touring at 0900 on the 15th.

Accident Summary

Terry Steward and Paula Varney had been recently hired by the Alta Lodge, and neither was very familiar with Alta and its ski runs. At about 1330, they left the top terminal of the Wildcat lift and headed down the west slope of Peruvian Gulch on a run known as Hasty Exit. This run was outside the patrolled ski area; the two skiers violated a closure to reach it. Skiers descending this run must negotiate a gap in a cliff band part way down. While skiing above the cliffs south of Hasty Exit, Steward triggered a small avalanche. He was knocked off his feet and then carried over the cliff, falling 80 feet to the rocks below! The avalanche continued down the steep incline below the cliff and carried Steward another 100 yards before coming to a stop.

Varney was not caught in the slide, but she lost sight of her companion as he was swept over the cliff. She decided the slope below was too steep for her to ski, so she took off her skis, left them there, and climbed down the cliffs ending up below Steward. She was unable to see him anywhere. She called out to him but received no answer. Deciding that help was needed immediately, Varney made her way down to the junction of the bypass road to Alta and the main road. She was picked up by Peter Lev, a visiting patrolman from Jackson Hole, who realized the seriousness of the accident and rushed back to Alta. The accident was reported at 1430 to patrol leader Bill Moss who immediately organized a rescue party.

Rescue

Two rescue parties were formed with all available patrolmen. Four men were sent up the Wildcat lift to drop in the top of Peruvian Gulch; four others along with Varney loaded a snow cat with a toboggan, resuscitator, oxygen, splints, and other emergency first aid equipment and headed for the scene. An ambulance was called from Salt Lake City to meet them at the junction of the main road and the bypass road where they would bring the victim out.

The snow cat was unable to reach the victim so the rescuers were forced to carry their equipment in on foot in a tough, uphill climb. Moss was the first to reach Steward's side. He found him on top of the snow in a half lying, half sitting position, conscious but in a bad state of shock and large lacerations on his head which proved to be fractures. He had been bleeding heavily from his head wounds, was coughing up blood, and was bleeding from his ears and one eye. It appeared to Moss that the victim had also suffered several broken bones, but because of Steward's state of shock, Moss was unable to communicate with him to find out what might be broken.

Steward was given first aid to stop the bleeding and was carefully loaded in the toboggan. He was carried downhill to the snow cat and then transported to the road where the ambulance was waiting. He was then taken to a Salt Lake City hospital where he remained in critical condition for several days. Steward's injuries were so severe that he never made a full recovery.

Comments

No matter how small, any avalanche that can sweep its victim over a cliff must be considered treacherous. This avalanche was classified as a SS-AS-2 and would have been harmless had the cliffs not been below. Few skiers enter this area because of the difficult terrain and marginal skiing conditions. Had the two skiers been more familiar with this area, they would have certainly picked another spot for their tour. On the day of the accident, this area had been closed to skiing because of avalanche hazard.

The rescue was carried out quickly and competently. Only an hour and fifteen minutes was spent from the time the patrol was notified until the victim was placed in the ambulance. Quick action saved Steward's life.

1 caught, partly buried, and injured

Weather Conditions

Crystal Mountain Ski Area had received only very light snowfall during November and early December. The study plot at the base area (elevation 4400 feet) had a total snow depth of only 9 inches on Wednesday, December 10; the ski area was not operating. Snow began falling on the 10th with 3 inches recorded on that day. On the 11th, 18 inches were recorded followed by 4 inches on the 12th. Temperatures remained cold during this period, and very strong west winds were blowing.

On Saturday, December 13, the snow turned to rain as warmer air invaded the region. Rainfall of 0.56 inch was recorded by 0800 on the 13th, and rain continued during the day. The temperature had warmed to 36°F. Several natural, wet loose slides had released on the steeper slopes.

Accident Summary

On the 13th, the upper part of Crystal Mt. was open for skiing. At about 1100, two pro patrolmen, Jerry Johnson and Buzz Franklin, were in the process of hand charging and ski checking the north and west faces of Exterminator, or Green Valley side of Exterminator. This area lies just above the lower terminal of the Green Valley chairlift.

Before controlling one avalanche path along the ridge, the two patrolmen conferred and decided to ski check it. Johnson made the first pass across the starting zone in deep, heavy, wet snow. Franklin then cut a track just below Johnson's. No avalanche released. They again conferred, deciding that Franklin would make another pass across the slope while Johnson skied over to a nearby chute.

Franklin began his second pass, got hung up in the heavy snow, and fell. When he hit the snow, the slope fractured 50 feet uphill and right along the line of Johnson's first ski pass. Franklin was only partially submerged as he was carried downhill but was swept into a stand of scattered trees. He was using neither pole straps nor ski safety straps, and as he hit the trees his skis and poles were ripped away. He came to rest a short distance below the trees in an almost standing position with only his head and one arm sticking out of the snow.

Johnson, who had witnessed the accident, skied down to help his buried partner. Franklin was freed within minutes, but he complained of severe back pains. He was taken by toboggan to the first aid room and then driven to the Enumclaw hospital. The diagnosis was several depressed or crushed vertebrae. Fortunately, Franklin made a full recovery and was back on skis again later in the winter.

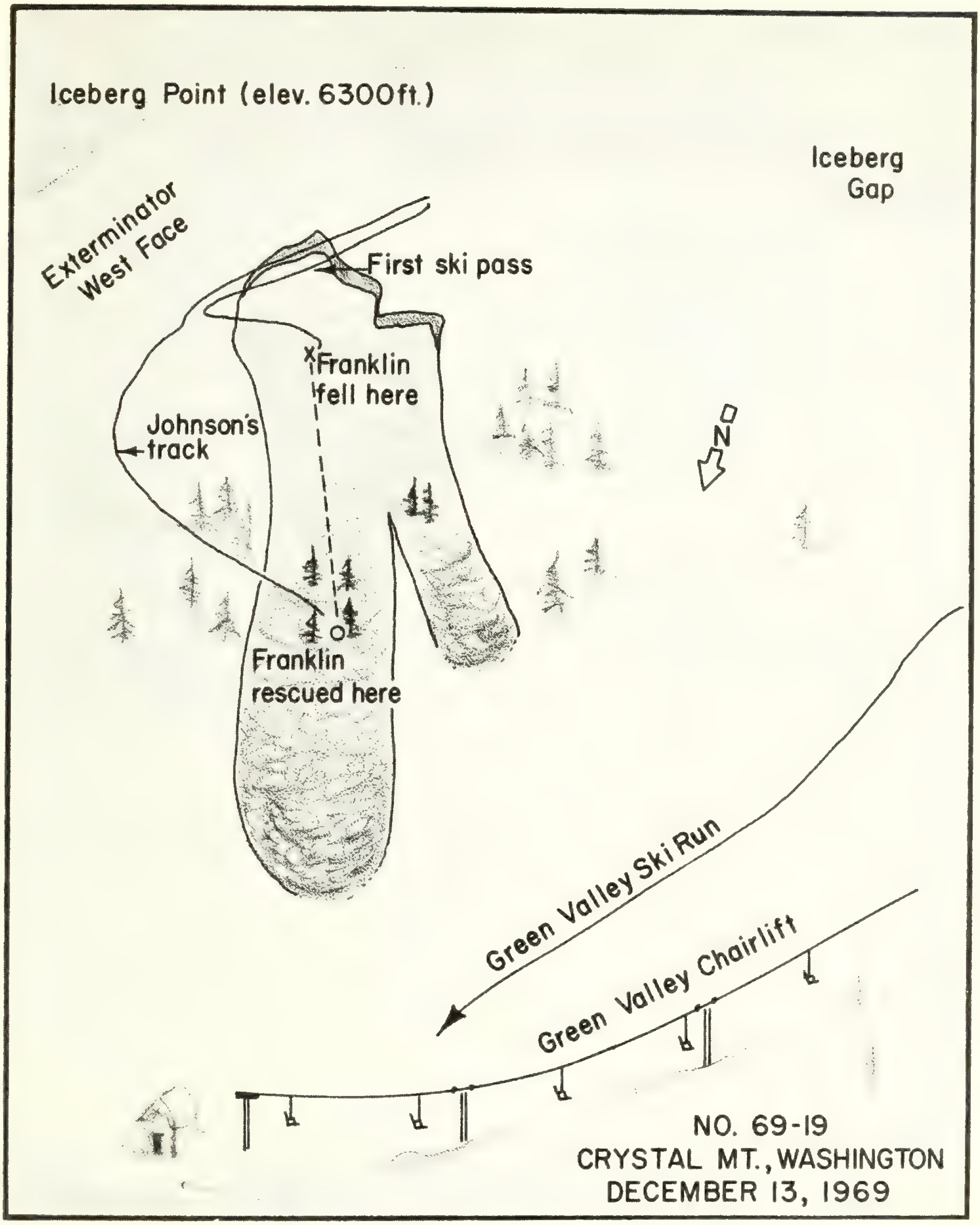
Avalanche Data

This was a medium-size wet-slab avalanche classified as WS-AS-3. Rain or a mixture of rain and snow was falling at the time of the accident.

The fracture line was 3 feet in depth, and only a shallow, hard crust of snow was left covering the ground. This north-facing slope, which lies just below 6300-foot Iceberg Point, has a steepness of approximately 36° in the starting zone. This avalanche ran the full length of its track, falling some 300 feet in elevation and coming to rest in Green Valley.

Comments

This avalanche path is too big and dangerous to be ski checked; it deserves a hand charge. Ski patrolmen need not take undue risks. Additionally, Franklin was skiing without pole straps or ski safety straps, which allowed his equipment to release when he hit the trees. This probably spared him from more extensive injuries.


Iceberg Point (elev. 6300ft.)
Iceberg Gap
Exterminator West Face
First ski pass
Franklin fell here
Johnson's track
Franklin rescued here
N
Green Valley Ski Run
Green Valley Chairlift
NO. 69-19
CRYSTAL MT., WASHINGTON
DECEMBER 13, 1969

4 caught

Weather Conditions

In early December 1969, a shallow snowpack lay over much of the Wasatch Range. A storm moved into the region on December 4 and snow fell daily for nine straight days. By the 12th, 36 inches of new snow had increased the snow depth at Alta from 17 to 39 inches. Temperatures had remained cold, rarely exceeding 20°F at any time until the end of the storm on the 12th. Then the temperature rapidly warmed, reaching a high of 48°F on the afternoon of the 13th. Winds had been strong and from the west on the 9th to the 12th.

Accident Summary

On the morning of December 14, a party of five experienced ski tourers left Alta and proceeded up to Cardiff Pass enroute to Lake Blanche. The group skied down the north side of Cardiff Pass on what appeared to be stable snow and then traversed below the east ridge of Mt. Superior. From this point it is necessary to traverse a broad, open bowl, climbing all the way to reach a saddle on Cardiac Ridge. From this saddle, it would be downhill all the way to Lake Blanche.

As the group began their traverse of the open bowl east of Cardiac Ridge, it became apparent that wind action had produced soft-slab conditions. They continued their climb and reached the final steep section near the ridge crest. In this area the snow had formed a uniform hard slab. The surface was so icy that the main concern of the skiers was to maintain their footing.

When the two skiers in the lead were within 100 yards of the saddle, a wide area of the slope broke loose 50 yards above them. Skiers 1 and 2, who had been highest on the slope, remained on the surface as the snow slid out from beneath them. They were carried on a fast ride but were not buried. Skier 3 was farther downhill and in the center of the slide area. He was hit hard by the avalanche and was tumbled downhill. Although he was buried several times during his ride, he came to rest on top of the snow. Skier 4 was nearer the edge of the slide and rode it on top of the snow. Skier 5 was below and to the right of the avalanche area and was not involved.

All five skiers were using special ski poles supplied by the International Vanni Eigenmann Foundation. These poles have an avalanche cord coiled inside the handle which can be ejected when necessary. In addition, the two poles can be joined together to form a probe pole. Before skier 3 was swept off his feet, he removed his skis and ejected the avalanche cord from one of his ski poles. Fortunately skier 3 came to rest on top of the snow, for his poles, skis, and the entire length of the avalanche cord were buried beneath the snow. It is not known whether any of the other skiers ejected their avalanche cords.

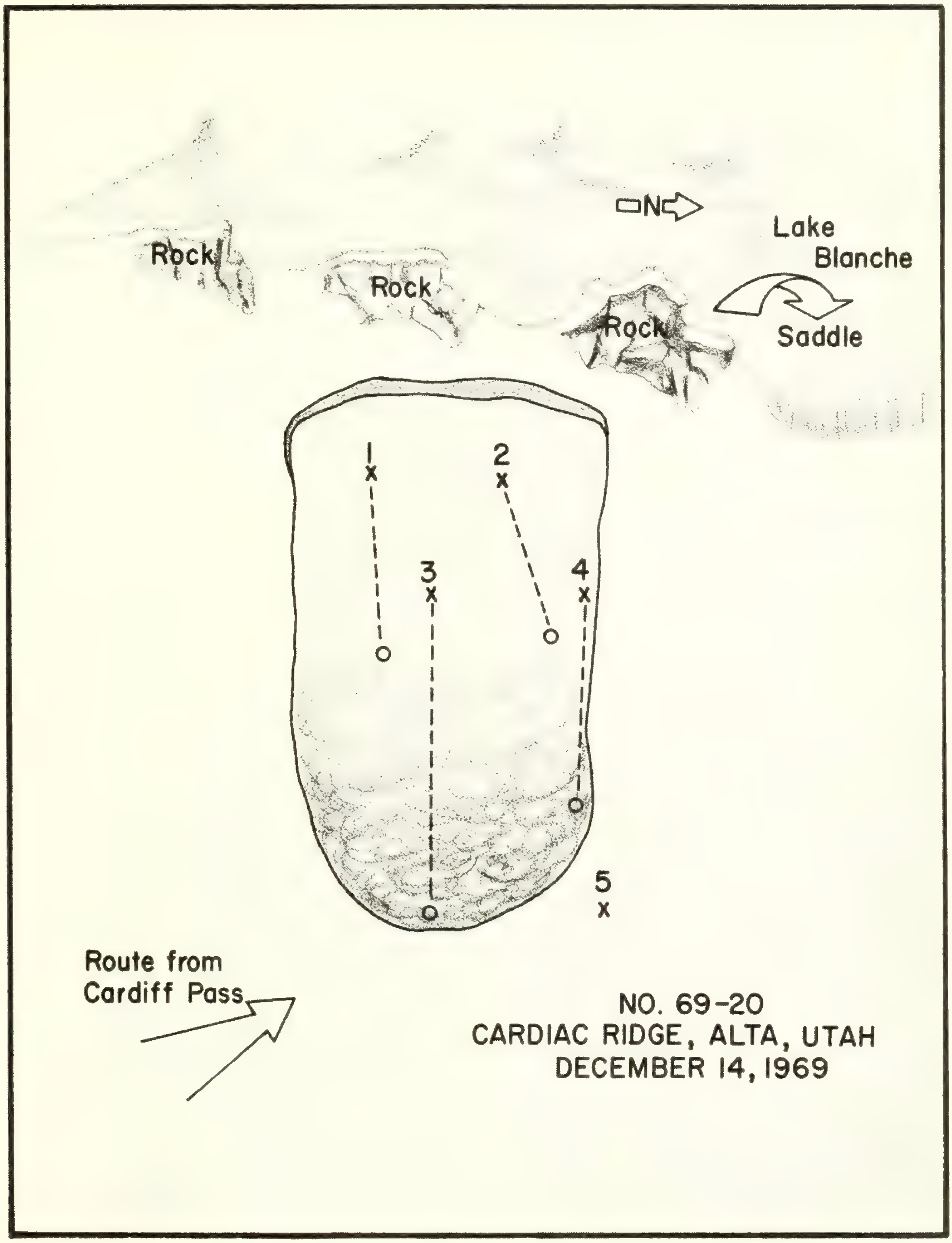
The group probed for the equipment lost by skier 3 and after 45 minutes finally found one ski and both poles. Skier 3 had suffered a twisted knee but still was able to walk out with the rest of the group via Mill D South Fork to the Big Cottonwood Canyon road.

Avalanche Data

This avalanche was classified as HS-AS-3. It ran on a steep, open, east-facing slope and had been formed by the strong west winds of a few days earlier. The fracture line was 2 to 3 feet deep and was about 225 feet in length. The slide ran about 900 feet slope distance and dropped a vertical distance of about 400 feet. A layer of depth hoar lay beneath the hard slab snow making a highly unstable snowpack when supporting four skiers.

Comments

The route taken by these skiers is strictly a high-hazard route. Most of the skiers taking this tour realize the danger but feel the rewards of the tour are worth the risk. However, there have been enough avalanche accidents on this route to make it taboo for the timid or the safety-conscious skier (see *The Snowy Torrents* No. 64-1. Another accident occurred in February of 1972.) There is simply no safe route across the cirque north of Cardiff Pass



NO. 69-20
CARDIAC RIDGE, ALTA, UTAH
DECEMBER 14, 1969

and east of Cardiac Ridge.

The buried avalanche cord is a rather disquieting circumstance of the accident. An avalanche cord is of absolutely no use if it is buried beneath the avalanche debris. Again, this incident and that in No. 67-9 are enough to cast serious doubt on the dependability of avalanche cords.

4 caught; 2 partly buried, and 1 buried; 2 injured

Weather Conditions

Early-season snowfall had been average in the Rockies of Colorado, providing an excellent snowpack for Christmas vacationers at the local ski areas. At Breckenridge, 25 inches of snow fell on December 24 and 25, increasing the total snow depth from 47 to 63 inches. This snowfall contained 1.53 inches of water equivalent, and strong west-to-northwest winds had formed widespread soft-slab conditions.

Accident Summary

A first person account of the day's events is given by Jim Hagemeier, a Forest Service landscape architect, who was involved in the accident: "On December 25, Christmas Day, I went to Breckenridge to ski with Snow Ranger Dick Shafer. He was out on avalanche control work, and I was unable to contact him until around 1245. At that time he asked me if I would like to accompany him, Al Britt of the N.S.P.S., and one of the ski area's professional patrolmen to look at a fracture line in the closed bowl (Horseshoe Bowl) to the north of the upper poma lift. We all rode up the poma lift then traversed over to the edge of the bowl.

"The bowl is around 1 mile wide and 1 mile long, from top to bottom. Average slope probably is around 32° and all of it offers avalanche hazard.

"Earlier in the morning the patrol had placed two charges in this area and produced a fracture line running the entire width of the bowl. The fracture line varied from 4 to 7 feet high on the far end. The reason for going to look at the fracture was not quite clear to me; however, it seemed that the primary purpose was to check the various snow layers and to see on which layer the avalanche had slid.

"Everyone put on his orange nylon avalanche cord except myself. (Mine, unfortunately, was down at the car.) We traversed out onto the slide area, directly below the 4-foot fracture line. Upon digging down into the snow, we found about 3 feet of crust and depth hoar still remaining in the slide area below the fracture line. At this time, I mentioned to Dick that it appeared very unstable to me. He reassured me that it had to be stable considering the amount of shooting and the size of the slide. I was still apprehensive about staying there, especially since I was the only one without an avalanche cord.

"The rest of the people had moved out away from me and we were all about 50 feet apart with Rick, the pro patrolman, in the lead; Al was next, then Dick, then myself. I thought I should be going back and turned to look for a safe way out. About this time I heard a sharp sound, like a clap of thunder, similar to a charge going off in the snow. My first reaction was that a charge had been set off, but as I looked upslope, I could see a new fracture line going across the top of the slope and the snow starting to move!

"Since the big load was still above us, there was not an immediate movement of the snow under my skis. I immediately turned my skis downhill into a shuss, thinking that I could reach a rock outcropping and possibly outski the slide. At this time I thought I was the only one caught in the slide.

"I had skied perhaps for a second or two when the major impact of the load above hit me, tossing me into the air and completely engulfing me. At this time I lost my poles and had a terrible feeling of panic. Several thoughts ran through my mind: first, I was a damn fool for coming there; and second, I fully realized the size of the slide and was certain that I would die.

"The feeling was of being dunked under water, as the impact took my breath away. For some reason, when I started to move with the slide, I could breathe much easier. I thought about the fact that I didn't have an avalanche cord and that it was up to me to get myself out of there. My right leg was being bent behind me by the pressure on the ski, which then released. Neither of my arlberg straps had been taken off; I am not really certain that this was a hindrance to me, though this thought occurred to me as I was engulfed in the slide. As it was, I got a good belt on the shins from one of my skis.

"The sensation of speed was fantastic; I had put my skis into a shuss on a 30° slope and was engulfed immediately. I remember the speed increasing as I went down the slope. The ride was very rough, and I was being tossed around quite a bit. It seemed as though I was in a big flume of water, where I was occasionally able to get a breath of air; but most of the time I was overwhelmed by snow.

"Later, individuals asked me if I had a sensation of which way was up or down. I can truthfully say that I was aware of up and down, at least after the initial shock of the slide hitting me. Initially, when the full blast of the slide struck me, I had no idea which way was which. As I moved downhill faster, I was able to orientate myself fairly well with the movement of the snow.

"I worked myself into a sitting position, with my feet downhill, and tried to swim as if treading water. This seemed to work, and I instantly started to rise in the snow. I kept doing this as I sped down the hill and increased the swimming motion as the slide began to slow down a little. Actually, it was not a fast decrease; it was just going very fast, then it started to stop slowly.

"I swam until I could feel the slide coming to a stop. I was still buried at this time. How deep, I didn't know, but it seemed deep! I pulled my arms in near to my head; at that minute the slide came to a rather abrupt halt, and I found my head and hands sticking up out of the snow. The snow was still moving very slightly, and I was able to work my body out to where I was sitting on the surface. I was able to pull my feet out and immediately release my arlberg straps."

Rescue

"My first reaction was that I was the only one caught. Then I turned and looked at the hill, and saw that the entire hillside had come down. I also saw the ski patrolman, Rick, still on his feet. He had been able to ski out of the edge of the slide. I yelled to him several times, asking if there was anyone buried. He finally answered that Al was buried. I ran toward the shouts and found Dick digging himself out. His head was downhill. He said he was okay.

"I then tried to regroup my thoughts, and remember where Al was before the slide took place. Everyone had 50-foot avalanche cords on except me, and we were all spaced fairly evenly apart. (It seemed natural to wait until the other fellow's avalanche cord was out before you started across the snow.) I remembered that Al was second in line, and started scanning the snow approximately 50 feet away from Dick. Looking uphill, I spotted a piece of orange cord protruding from the snow. I ran to the cord and yelled to Rick, who was then below me, that I had found Al and to go for help.

"I used the cord to pull myself up the snow, to where it disappeared into the snow. I made one swipe with my hand, a little ahead of the cord, knowing it was tied around his waist. The second swipe hit an object, and I was able to dig out Al's head. His head was approximately 14 inches or so below the surface. I continued digging until I got his head fairly free; he was still conscious. Dick arrived at this point and seemed to be okay but complained about his knee hurting him. As it turned out, he had a slight fracture of the lower leg.

"At that time I glanced at my watch, it was 1325. The slide had occurred at approximately 1315; it had taken me about 5 to 7 minutes to get myself out of the slide, find Al, and free his head. Although he was still conscious, he appeared to be going into shock. We continued to dig around Al until the first party arrived about 25 minutes later. Two patrolmen arrived with the toboggan, and three others stood on a rocky ridge where they could act as lookouts and be available to help if they were needed. The patrolmen administered first aid to Al and loaded him in the toboggan.

"Dick and I both had ended up in little gullies at the bottom, while Al was buried on a flat plane, almost a ridge. When I went to retrieve my skis and to ski out of the area, I noticed that the deposit on top of the old slide where my skis were sitting was approximately 10 feet deep. I actually had to climb up onto the ridge of snow to get my skis. I went down to join Dick, because the patrolmen were now handling Al. I started to get real nervous about the snow hanging above us. The patrolmen waiting on the hill continued to yell to us to get out and later asked why we didn't. The reason was that Dick's leg was hurting him, and he felt he could get out a lot easier on skis, in the deep snow, than by walking. But first he had to retrieve one of his skis, which was buried fairly deep. I started out first and met the snow cat, which was coming up to the base of the slide area to pick up Dick and Al (on the toboggan).

"As far as injuries go, I was perfectly okay, though later in the evening and the next morning, I felt as though I had played football all day. Dick had a wrenched knee, which we later discovered was chipped. Al, other than going into shock, had muscle spasms and a cracked pelvic bone, which was discovered later."

Avalanche Data

The first avalanche had been artificially triggered by hand charges, releasing the entire bowl for a distance of about half a mile. This slide was a SS-AE-4, ran 900 feet vertically, and had a 4- to 7-foot-deep fracture line. The second avalanche was triggered by the skiers, releasing about 200 feet above the first fracture line. This one was a SS-AS-4 with a 4-foot fracture line which extended about 300 feet in length. A thick layer of depth hoar—15 to 30 inches in depth—lay at the ground beneath the slab. The second avalanche dug to the ground in parts of its track. Debris was 10 feet deep in places.

Comments

This accident is very instructive in several ways. First, it points out the danger from a hanging snow slab after an avalanche has released lower on the slope. If there is still plenty of snow above the fracture line, the slab is usually unstable by virtue of having no support from below. It is a situation to be avoided.

It is speculated that the second avalanche was triggered by skiers walking on the bed surface of the first avalanche. Their weight placed enough stress in the slab far uphill to cause failure. In this case, the fracture line should have been inspected by one person at a time, and this person should have been on belay. The weight of the four skiers was more than the slope could support.

Another important point is the effectiveness of swimming with the slide as reported by Hagemeier. He swam on his back, head uphill, as though treading water. (However, his skis were still attached so leg movement was hampered.) He was able to swim effectively even though his skis were still dangling from his boots by his arlberg straps. Dick Shafer on the other hand, was knocked forward by the slide and swam on his stomach, head downhill, as though he were doing a breast stroke. Both men were able to maneuver in the snow, putting them less at the mercy of the avalanche. Hagemeier is strongly convinced that swimming did a lot toward saving his life.

Most important though is that this is the first documented case in which an avalanche victim was saved because of his avalanche cord. Al Britt and all his ski equipment were completely buried, but a section of his avalanche cord was on the surface. The avalanche cord proved its value and worked the way it was intended. This, though, is not always the case, as exemplified by Nos. 67-9 and 69-20. The avalanche cord should be used, but the user should realize it is not 100 percent reliable.

In retrospect, Hagemeier had some final thoughts on the outcome of this accident: "Looking back on the whole operation we can no doubt say we were extremely fortunate not to have anybody killed. Personally, I feel extremely lucky not to be dead at this time. It was an awful incident, and one which we need not have experienced had we used a little sense. However, it is worthwhile to pass this on to other individuals.

"In conclusion, I might say that it was probably the best Christmas gift I have ever had in my life to end up sitting on top of this slide."

No. 69-22 Mt. Cleveland, Glacier Natl. Park, Montana December 29, 1969

5 caught, buried, and killed

Accident Summary

On December 26, 1969, five young climbers contacted Glacier National Park Ranger Robert Frauson at his home at St. Mary on the east side of the park. The five were Jerry Kanzler, 18; James Anderson, 18; Mark Levitan, 20; Clare Pogreba, 22; and Ray Martin, 22. They planned to climb the north face of Mt. Cleveland which, at an elevation of 10,448 feet, is the highest peak in the park.

Frauson, an experienced mountaineer, tried to persuade them not to climb Mt. Cleveland in winter. He mentioned the severe and unpredictable weather conditions, avalanche hazard, and the time required to obtain rescue service should they need help. Frauson failed to dissuade the group from making the climb, but they did agree to climb the west face rather than the more difficult north face.

The five climbers camped overnight at St. Mary and departed early on the 27th for Waterton Townsite in Canada. They hired the services of a Waterton resident to transport them by boat to the south end of Waterton Lake, a trip that carried them back into the United States. From this point, they began a crosscountry hike toward Mt. Cleveland which is located 3 miles to the southwest. This was the last time the five young men were seen alive.

Rescue

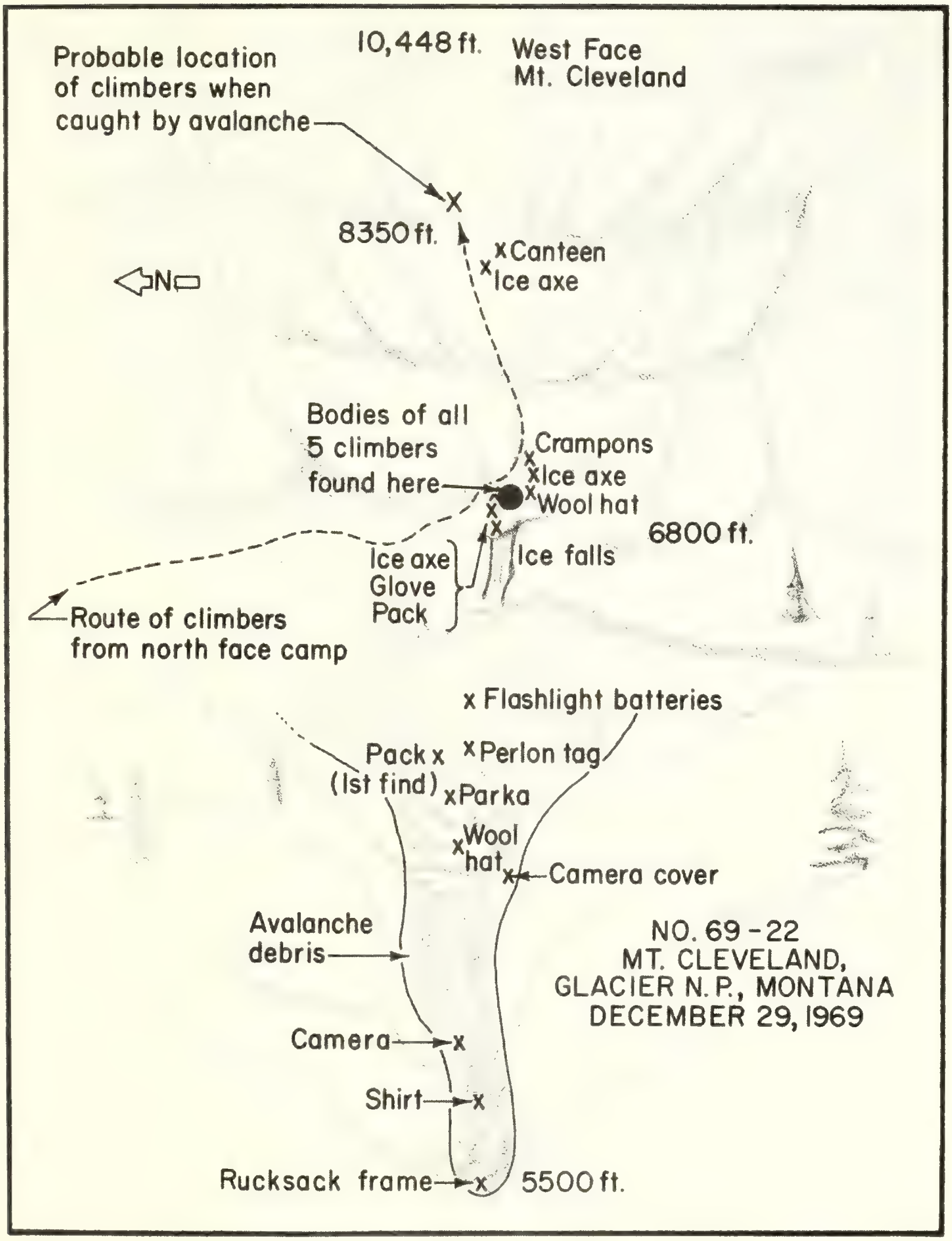
On December 31, Bud Anderson, the older brother of James Anderson (one of the climbers), flew over the Waterton and Mt. Cleveland area to check on the location of the five climbers. He saw what he thought were their tracks leading into a fresh avalanche about halfway up the west face of the mountain. Also, other tracks appeared to leave the avalanche site, but he was not certain of this latter observation. Anderson figured that the climbers should be able to complete their climb, barring an avalanche misfortune, by the following day, January 1, 1970.

On January 2, Anderson and a Waterton National Park Warden went by boat to the south end of Waterton Lake. No signs of the five climbers were found here. The two men returned to Waterton Townsite and contacted the Chief Park Warden's office. The Glacier National Park Superintendent was notified of the unfolding emergency situation, and an initial search and rescue operation was launched to locate the overdue climbers.

An air reconnaissance was begun early on the afternoon of the 2nd, and two men began hiking in following the climbers' tracks from the Waterton Ranger Station at the south end of Waterton Lake. The air search revealed no visible signs of the climbers, but the pilot did see the avalanche on the west face and reported either animal or human tracks leading into and out of it. The two ground searchers found a pair of skis and snowshoes belonging to the climbers about 1½ miles from the lake. The climbers' tracks were headed toward the north face of Mt. Cleveland. A ranger was sent to the Waterton Ranger Station to remain there in case the climbers should return during the night.

Early on January 3, two ground parties headed toward Mt. Cleveland. One party planned to search the northwest ridge route; the other would check beyond where the ski and snowshoes were found the previous day. About ½ mile above this latter point, the searchers found a camp with four backpacks, two tents, climbing gear, and a cache of food; this was about ¼ mile below the north face of Mt. Cleveland. Tracks were followed from this camp into the cirque below the north face where two snow caves were found. However, the caves had not been used as a bivouac site.

At this time it was evident that the five missing climbers had run into trouble; whether they were still alive was not known. Also, it was unknown whether they were on the north face or the west face of the mountain. Avalanches had been spotted on both the north and west faces. A full-scale rescue operation was launched on the 3rd with requests for technical climbers from Bozeman and Butte, Montana; from Grand Teton National Park; and from Jasper National Park in Canada.



NO. 69 - 22
MT. CLEVELAND,
GLACIER N. P., MONTANA
DECEMBER 29, 1969

The rescue climbers assembled on January 4 and began their search on the morning of the 5th. They organized into five groups assigned to cover the north face, the northwest ridge, the upper west face, the lower west face, and to man an observation post on Goat Haunt Mt., from which the north face of Mt. Cleveland could be observed.

Visibility had now improved and the air search, which had been hampered for the past 2 days was reinstated. A helicopter was used to make a close inspection of the north face; this revealed no trace of the five climbers.

The north-face searchers found no traces or signs of the missing climbers. However, the searchers on the northwest ridge found tracks leading up from the north side and then back down again. It was guessed that one or two of the missing climbers had used this ridge for a visual study of possible routes up the north face and then returned to the north side. The upper west-face group found no clues. Darkness caught them high on the face, and they were forced to bivouac there overnight. The lower west-face searchers also found nothing but they had been unable to work the avalanche debris because of the danger caused by climbers above them. The Goat Haunt observation group produced only negative results. All the other climbing parties, including the Goat Haunt observation personnel, were off the mountain by nightfall.

On January 6, probe lines were established across the north-face avalanche debris. At the same time, the support climbers who had bivouaced on the west face moved down to the debris area of the west-face avalanche. In early afternoon, this group found a pack belonging to the missing climbers; it was on the surface of the west-side avalanche and covered with a light skiff of snow. When this was reported, all but six men were immediately flown by helicopter from the north to the west side. Probing revealed a buried parka containing a camera and a can of film. The film was flown out and processed within hours but did not reveal any new clues.

On the 7th, although 80 percent of the west-side avalanche had been probed, and the same area covered with a magnetometer, no new clues were discovered. Most of the debris, however, was deeper than the 12-foot probe poles being used. The remaining area was probed on the 8th, again with negative results.

On January 9, a major storm struck the area, making further search efforts impossible. For several days the search team had realized there was no hope of finding any of the five missing climbers alive. So when the storm struck, a press release was issued through park officials stating that the search was suspended for the winter. This decision was made after consultation with the parents and relatives of the missing climbers.

The following spring, when the snow began to melt, foot patrols were sent in every few days to search for new evidence. During this period, the west-face area of Mt. Cleveland was closed to public use. On May 23, a camera was found containing film that placed all five climbers on the west side. The next clue came on May 25 at the 8,300-foot level when an ice axe was found. During June, several additional pieces of climbing gear were found below the ice fall and at the toe of the avalanche. In late June, it was decided to make a summit climb to see if one or more of the bodies were hung up on the upper west face which had now melted free of snow.

On June 29, five men began the climb. Upon reaching the top of the ice fall, the men noticed a strong odor accompanying the melt water flowing from beneath the snow. A flashlight beam was aimed up the streambed beneath the snow; the first body was seen 30 feet upstream. The body was reached by digging down through 6 feet of snow; it was identified as Ray Martin. Tied to the body was a red perlon rope which extended uphill and disappeared beneath the snow. Trenching and probing revealed the second body, that of James Anderson, under 14 feet of snow. However, the body of Anderson was not tied to the red rope but rather to a gold one. From here, both the red and gold lines disappeared uphill into the snow.

The search was ended for the day with plans being made for the recovery of the other bodies. Film from Anderson's camera had been developed several days earlier. The last picture taken indicated that Jerry Kanzler should be at the other end of the red rope and that Mark Levitan would be in the middle and Clare Pogreba at the end of the gold line. All these expectations were later confirmed.

The final recovery effort began on July 1 and continued through the 3rd, three days of hard, unpleasant work. Probing, trenching, and eroding the snow with water using a nozzle, hose, and gravity-sock setup were all used to excavate the bodies from beneath more than 18 feet of snow and ice. Finally, on the afternoon of the 3rd, the bodies of the last three climbers—Kanzler, Levitan, and Pogreba—were removed and flown out by helicopter. All rescue operations were concluded that evening: and the west face of Mt. Cleveland was again opened to the public.

Comments

Mountaineering is dangerous, particularly in winter; that is part of its appeal. Regardless of the expertise and the preparedness of its devotees, this sport will continue to claim its victims. However, undue risks can and should be avoided. The advice offered by rangers should always be heeded: they know their mountains well.

The Mt. Cleveland tragedy occurred in December 1969 but was not closed until July 1970. It marked the greatest number of deaths in the United States in a single avalanche since seven were killed at Twin Lakes, Colorado in 1962 (see *The Snowy Torrents* No. 62-3). The five young climbers—two on one rope, three on another—were high on the west face at about the 8,400-foot elevation when they released an avalanche or were struck by one released above them. They were swept to the 6,800-foot elevation where they were hopelessly buried under tons of snow and ice. The avalanche occurred on either December 29 or 30, as best as can be determined.

The rescue was a major effort that was conducted as logically and smoothly as was possible under the circumstances. Search and rescue was conducted by United States and Canadian park personnel and involved support climbers from both the United States and Canada, and helicopter support from the United States Air Force and an independent flying service. Logistics was a major problem: men and equipment were transported to and from the mountain by boat on Waterton Lake until the lake froze; then by helicopter when weather permitted; and overland by skimobile. Total cost of the search and recovery exceeded $19,000. Both the search and recovery efforts received national publicity, being covered extensively by radio, TV, and newspaper.

1 caught and partly buried

Weather Conditions

Precipitation had fallen at Alpental every day from January 8 to 24. Daily snow amounts ranged from 1 to 14 inches, but water equivalents were high because some of the precipitation fell as a mixture of rain and snow. On the morning of the 23rd, 4 inches of heavy snow containing 1.24 inches of water was recorded. Eight additional inches had accumulated by the afternoon of January 24. Avalanche control on the 24th produced several medium-size avalanches.

Accident Summary

At about 1530 on the 24th, two young skiers, Diane Boender and Keri Coughlin, got off the upper chair and headed down International. At the bottom of this run the two girls decided to go through the trees to find untracked snow. They skied over to a run named Dom and started down. From somewhere above them, the snow broke loose and ran down the slope behind the two skiers. Boender was hit by the moving snow, but Coughlin escaped to the side.

Boender felt the snow pulling her down. She instinctively remembered that avalanche victims should try to swim with the slide. She thrashed her arms and this effort helped keep her head up. The avalanche carried her about 100 feet downhill before coming to a halt. She was buried chest deep in heavy snow. Her friend Coughlin, seeing she was apparently out of danger, skied down to summon help.

Rescue

Coughlin notified the lift attendent at the bottom of Chair 1, who in turn called the ski patrol at the top of the chair. Several volunteer patrolmen skied to the accident site to help the victim. Boender had a great amount of trouble digging herself out of the debris; the patrolmen then arrived and helped her out. All her equipment was intact, and she skied on down the mountain.

A short time later, the Alpental pro patrol learned of the accident and questioned the volunteer patrolmen to see if anyone else was involved in the accident. The volunteers had not questioned the two girls and had failed even to get their names. Assistant Snow Ranger Jack Gihlstrom was notified, and he in turn notified by radio Snow Ranger Ken White who was at a nearby ski area.

When White arrived at 1630, Gihlstrom and some of the pro patrol had already headed for the avalanche area with probes. They were proceeding on the possibility that other skiers could have been buried by the avalanche. Meanwhile, White stayed at the base area to try to find the girls who were involved in the accident. He finally found Boender who said she thought she and Coughlin were the only skiers near the Dom avalanche. To be absolutely certain there were no remaining victims, the searchers coarse-probed all the debris, which measured about 200 by 400 feet and was 4 feet deep. The results were negative, and the search-and-rescue efforts were concluded at 1735.

Avalanche Data

This avalanche was a point-release slide that started in a cliff area above the Dom ski run. This release point is above the normal control zone of this slide. It is unlikely that the two skiers triggered this avalanche; more likely, they were victims of a natural release in the cliff area. This avalanche most probably was a L-N-3. Starting in the cliff area, it ran some 500 feet down the slope, piling debris 4 feet deep.

Comments

The rescue work following this accident emphasizes an important point: *if there is any suspicion that there could be a buried victim, search the avalanche first and ask questions later.* This does not mean that a handy witness should be disregarded, for he may provide a life-saving clue. But time should not be wasted trying to track down unavailable witnesses.

It is important to remember that if skiers are on the mountain, every sizable avalanche is a potential threat. If skiers were known to be in the area, it is mandatory that the avalanche area be searched (and probed, if warranted) for possible victims. There is always a chance that an unseen skier could have been buried. A tragic example of this is provided by No. 70-2.

In this accident, an initial mistake was made by the first rescuers when they failed to question or hold the witnesses and failed to initiate a hasty search of the avalanche area. The pro patrol and assistant snow ranger acted correctly by initiating a coarse probe of the debris before trying to locate the witnesses.

4 caught; 2 partly buried and 1 buried; 1 killed

Weather Conditions

A large storm moved into the Wasatch Range in Utah on the afternoon of January 27. By the morning of the 29th, 37 inches of snow had fallen, increasing the snow depth on the ground from 74 to 101 inches. The snow had a water equivalent of 2.87 inches. The temperature was in the middle twenties when the storm began but had dropped to 2°F on the 29th. Winds averaged 25 m.p.h. from the west and west-northwest with gusts to 45 m.p.h.

Avalanche control was carried out early on the 29th with several small and medium avalanches being reported, enough to raise suspicion especially with 3 feet of new snow. The Lower Peruvian Ridge route was run by two patrolmen. They threw three hand charges (one of which was a dud) and ski checked the ridge area, releasing a few minor sluffs. The chute in which the accident later occurred was not controlled with explosives but received two ski cuts. No signs of significant instability were seen in this area; therefore, at about 1030 the Peruvian Ridge area was opened to the public.

Accident Summary

At 1145 a group of skiers unloaded from the Wildcat lift and headed for the Lower Peruvian Ridge area for the purpose of filming a promotional movie of skiing at Alta. The party consisted of four Alta ski instructors, including Max Lundberg and Alf Engen, and two cameramen. As they left the lift, some of the group spoke to Ted Manusama, a local skier and employee of the Alta Lodge. Manusama was interested in the movie project and followed behind the party as they traversed towards Lower Peruvian Ridge.

They arrived at the slope where the movies were to be taken and began setting up. Lundberg and Engen were to ski down toward the two camermen who had spaced themselves lower on the slope. The other two men were to observe from above and ski down later. The four ski instructors began a short hike to reach the top of the ridge and, preoccupied with their project, lost track of Manusama. The last time any of the skiers or cameramen noticed him, he was to the side of the slope that was to be skied.

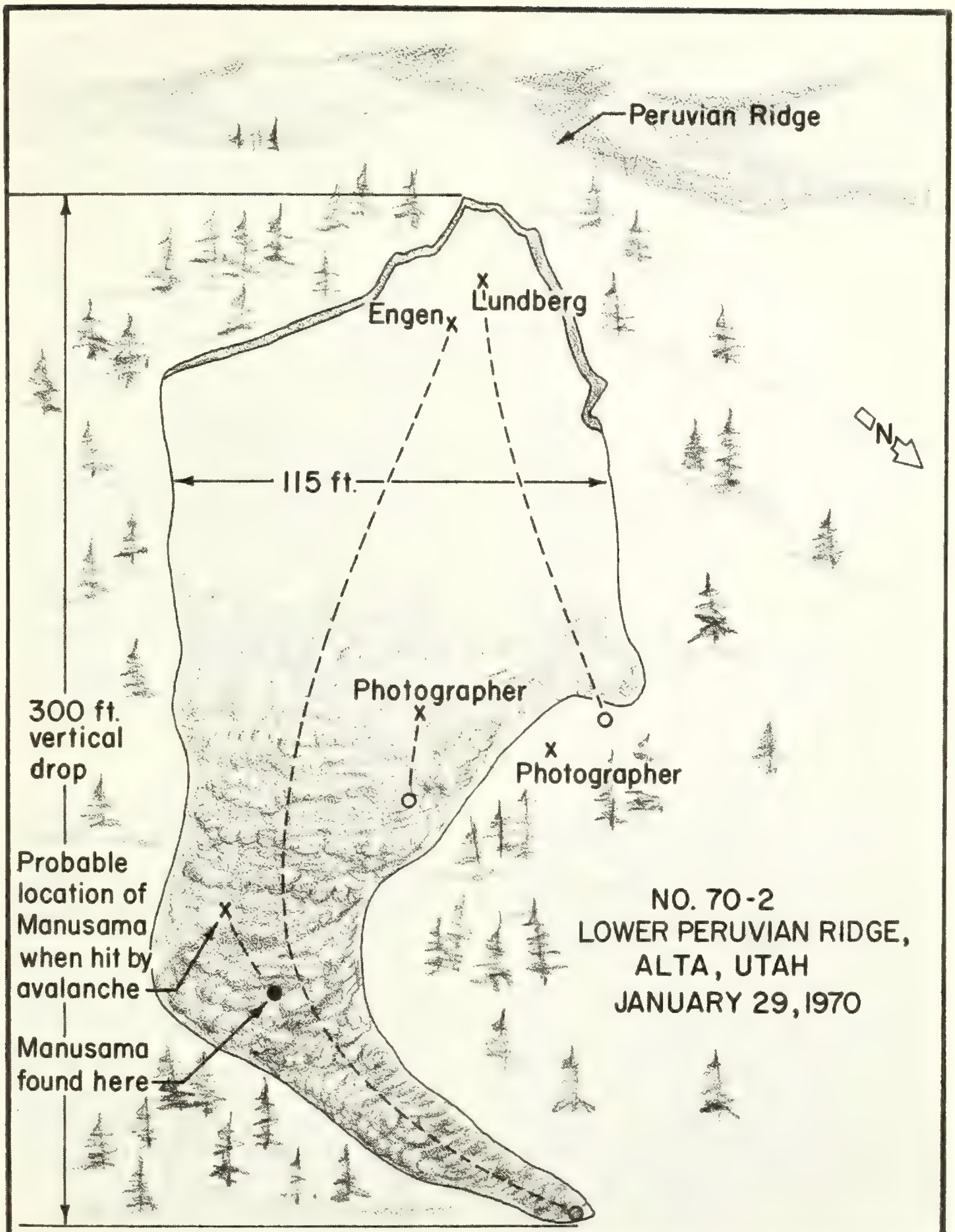
Lundberg and Engen began their descent, and the cameras began rolling. Both skiers had made two turns, Engen farther downhill than Lundberg, when the snow fractured above and around them. Lundberg didn't see the snow fracture but knew for some reason he was having trouble keeping his balance. He then realized he had been caught in an avalanche and struggled to keep his feet. He maintained his balance, skied with the slide, and came to a stop at the edge of the moving snow.

Engen saw the snow fracture out of the corner of his eye. A powerful skier, he pointed his skis straight downhill trying to ride the slide out. With a lot of snow above him and overtaking him, he had trouble standing up in the churning mass. He gained speed quickly and zoomed downhill and out of sight as the avalanche turned a corner below a small knoll.

One of the cameramen was directly in the path of the avalanche. Engen almost hit the man as he shot past, but there was no way for the cameraman to avoid being hit by the avalanche. The avalanche struck with force, scattering his equipment and sending him somersaulting downhill. He was buried to the neck when the slide came to a stop. The other cameraman was to the side of the avalanche and was not caught.

Rescue

After the slide had stopped, those who were not caught began counting heads. Lundberg was all right on the edge of the slope. The buried photographer was spied, his head sticking above the debris. That left only Engen who was nowhere to be seen. They assumed he had been buried in the slide and began probing with ski poles. One of the members left the group to ski to the bottom for help. Following the slide path down, he turned the corner around the knoll and saw Engen climbing back up the debris. He had ridden the slide to the


Peruvian Ridge
Lundberg
Engen
115 ft.
300 ft. vertical drop
Photographer
Photographer
Probable location of Manusama when hit by avalanche
Manusama found here
N
NO. 70-2
LOWER PERUVIAN RIDGE,
ALTA, UTAH
JANUARY 29, 1970

very toe, unobserved by his companions.* After Engen had been found and the photographer dug out, it was mutually agreed that everyone was safe and no other person had been involved.

Two skiers riding the Wildcat lift had witnessed the avalanche. They had been watching the filming party and, moments before the avalanche occurred, had noticed a skier in an orange parka. Although this skier was in the same general area as the filming group, he was obviously not involved in the movie taking. The two witnesses paid no more attention to the skier in the orange parka, especially once the avalanche released and they became engrossed in watching the slide.

Finally the two witnesses unloaded from the chair, skied to the accident site, and asked if they could help. It was just then that Engen was located, so the two witnesses were told everyone had been accounted for. The two witnesses then skied off.

Meanwhile, one of the filming crew had skied to the bottom and reported the accident to the pro patrolman on duty. The patrolman was told that apparently everyone had been accounted for but that possibly Ted Manusama had been caught since he was in the Peruvian Ridge area. The patrolman began organizing a rescue and contacted Snow Rangers Bengt Sandahl and Will Bassett by radio. Sandahl was on the mountain and skied to the accident site; Bassett went to the bottom and helped organize a rescue team.

Sandahl arrived at the accident site and questioned those involved whether anyone else had been buried. He was told that Manusama had been with the party earlier but had skied off. A set of ski tracks beyond the avalanche area were identified to Sandahl as probably belonging to Manusama. At this time, the two skiers who had witnessed the slide from the chair once more skied up to the site. They told Sandahl they had seen a skier in an orange parka nearby but thought he could not have been anywhere near the avalanche. Sandahl was then told by the movie makers that Manusama was wearing an orange parka. To finalize the consensus that Manusama couldn't have been buried, the two skiers who had started the slide, Lundberg and Engen, said pretty definitely that they were the only skiers caught by the avalanche.

Sandahl then skied down to where Bassett and the ski patrol were leaving for the rescue. Some rescuers had already started up. The snow rangers and patrol weighed all the eyewitness reports of the six skiers in the movie party and the two skiers on the chairlift. The consensus was that Manusama had skied out of the area before the avalanche began and could not be buried. The rescue was, therefore, called off, and the rescuers who had started up were called back.

At 1700, after the lifts had closed, the Alta Lodge was checked; Manusama had not yet reported for work. Ski patrol leader Jim Head had just returned from sweep when the Alta Lodge called. Head immediately told all patrolmen to get their skis on, and the rescue was set in motion. The first probe line consisting of about 14 probers was set up at about 1800. At 1830 the body of Ted Manusama was found, clad in an orange parka. He was located under 3 feet of snow, head downhill and no indication of an ice mask around the face. All his ski equipment was intact, indicating he had been carried only a short distance by the avalanche.

Although oxygen was administered immediately, Manusama showed no signs of revival. He was pronounced dead from asphyxiation at Cottonwood Hospital in Salt Lake City.

Avalanche Data

This avalanche was a SS-AS-3. It was 115 feet wide in the starting zone and fell 300 feet vertically. The fracture line was 3 feet deep, failing on a very steep slope of 47°, This particular slope along Lower Peruvian Ridge has a northeast exposure.

The toll for this avalanche was four caught, two buried, and one killed. The two skiers who triggered the slide survived; the victim, unseen by the others, was low on the slope and was buried deeply by the large amount of snow descending from above. As in so many other avalanche accidents, this points out that the persons lowest in the track are in the greatest danger.

Comments

The lesson to be learned from this accident is very simple, very blunt. It is this: *the safety of skiers is not best served by inaction after an avalanche accident*. The possibility exists that, for any avalanche large enough to bury a person in any ski area, an unseen skier could have been buried. This is a principle that cannot be compromised. Accordingly, avalanche rescue policy at all ski areas should be rigid on this one point: every avalanche suspected, however slightly, of burying a skier must be probed without exception. Alta now adheres strictly to this policy.

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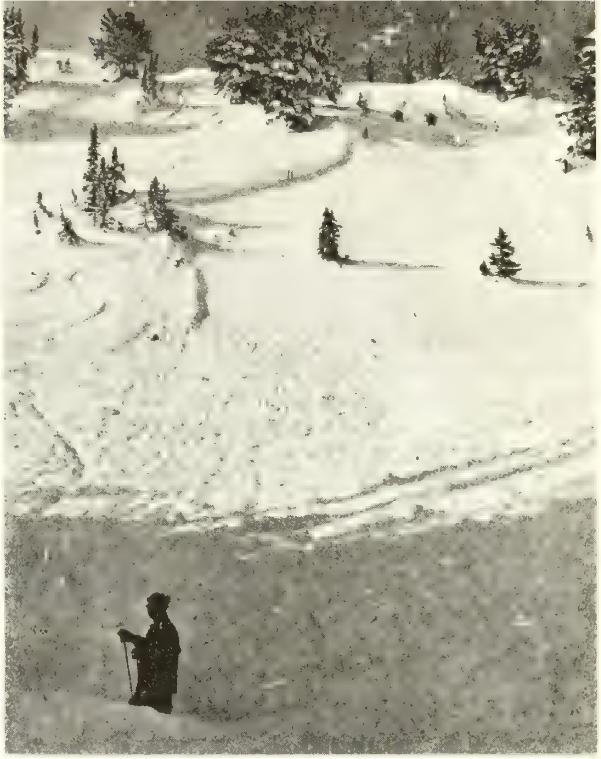
* In a skiing career of 40 years, this was Engen's third escape from a major avalanche. In all cases, he kept his skis on and skied out of the slide.

The decisions of rescuers must not be based solely on the reports of witnesses but must include all possibilities. Admittedly the eyewitness reports following this accident were mostly unanimous and convincing that Manusama could not have been buried. Nevertheless, he was known to have been in the area at the time of the avalanche, and his presence following the accident was unaccounted for. Thus, strict policy should have been followed and a rescue initiated. The hard fact remains that the victim would have been found within 90 minutes instead of 6 hours. Would this have saved his life? This question cannot be answered, but no buried victim should ever be denied this chance.

Finally, this accident starkly points out the danger of skiing alone. Manusama was skiing alone and therefore was not actually missed until later in the day. A skiing companion would have sounded an immediate alarm, giving Manusama an excellent chance of survival.



No. 70-2. Lower Peruvian Ridge, Alta, Utah. This photograph showing the fracture line in Lower Peruvian Ridge was taken the day after the accident. The figure at the bottom is standing at the spot where the victim was found.

3 caught; 1 partly buried, and 1 buried

Weather Conditions

On February 15, a storm moved across northern Idaho bringing heavy snows to the higher elevations. By the morning of the 16th, 18 inches of damp, heavy, new snow had fallen at Schweitzer Basin Ski Area and increased the total snow depth to almost 90 inches. The storm was still in progress on the morning of the 16th with the temperature holding at 31°F.

Accident Summary

Before the lifts were open to the public on the morning of the 16th, two ski patrolmen, John Pucci and Phil Owens, and a ski instructor, Glenn Phillips rode up Chair 1 to test ski a slope near the chair called the Face. Pucci and Owens worked the south side of the Face with no results. Phillips worked down the north side and released several small sluffs. He then traversed across the center of the slope and ended up on the south side, about 50 feet below the two patrolmen. He came to a stop with a hard jump turn; immediately the entire south side of the Face fractured and was set in motion. The fracture line broke 90 feet upslope of Phillips and 40 feet above Pucci and Owens. All three men were caught by the slide.

Owens was nearest the edge; he was carried 150 yards downslope and came to rest on top of the snow. Pucci was carried 175 yards and was buried to the waist. Phillips was hit by the main part of the avalanche; he rode on top for the first 20 yards but then was pulled under. He was carried a full 250 yards to the toe of the debris. In his own words, Phillips describes his experiences:

"I skied to a stop about 50 feet below Pucci and Owens and then everything started moving. I remember calling out as I looked up the hill and saw them floundering, so I knew it had fractured above them. After I went under the snow the problem was to try and keep the snow out of my mouth. I can remember coughing violently and trying to keep my hands over my mouth which was nearly impossible. Somewhere along the line, my ski cap was pulled down over my nose and mouth. This made breathing less difficult. The wet snow tossed and turned me quite violently during the ride down. I remember two very solid jolts, as if I had been slammed against the ground. I had removed my wrist straps and lost my poles immediately, but my skis did not come off and it seemed as if they were pulling me under as I slid. When the slide stopped I was face up, two feet under the snow, with my feet downhill. My left hand was near my mouth and I managed to punch a small hole for breathing and also to push up my hat which had slid down over my face. As I did this, I noticed that it seemed lighter above me. I punched violently upward with my left hand and my fingers broke through the snow. I kept trying to enlarge the hole, but in the process knocked loose snow into my mouth, making breathing difficult. It was this hand movement which was seen from the chairlift and led to my being quickly dug out by the rescue crew."

Rescue

Two other ski patrolmen had also ridden up the chair. They remained at the top terminal and were provided with a ringside seat to the whole avalanche. When the snow came to a halt, they could see only Owens and Pucci on top of the snow. They phoned to the bottom for rescue assistance and then skied over to Owens. He was unharmed and on top of the snow; all three then proceeded to Pucci and dug him out.

No signs of Phillips were yet seen. All four men began working their way down the slope searching for clues. At this time, the first member of the rescue party was on the chairlift and spied a gloved hand sticking above the snow near the toe of the avalanche. He shouted to the four men on the snow and directed them to the spot.

Phillips was found with his head 2 feet beneath the snow; one arm was jutting upward and his hand was on the surface. Gasping for air, he was immediately uncovered and helped from the snow after being buried only a few minutes. All three men who were caught suffered slight injuries but gained valuable experience from their ordeal.

Avalanche Data

This slide was a SS-AS-3 which resulted from shallow instability in the new snow layer. The Face is a fairly steep east-facing slope (34° near the top) that is skied regularly. The few trees scattered on the slope were not numerous enough to anchor the snow cover. The avalanche was some 75 yards in width and 300 yards in length.

Comments

Test skiing should be programed only on small slopes. This slope—the Face—is much too large for test sking and should have been controlled with explosives before being skied. In addition, this group's test-skiing technique leaves much to be desired: it exposed all three members of the team to danger. Only one skier at a time should have been exposed while the other two stood at points of safety.

A number of avalanche victims have been quickly rescued alive because they had thrust a hand upward, reaching the surface (see No. 67-9 for example) just as the avalanche was coming to a stop. This is certainly one way that avalanche victims can help themselves and should be considered as important as forming an air pocket.

1 caught, buried, and killed; 1 vehicle damaged

Weather Conditions

Snow began falling over the San Juan Mountains of southwestern Colorado on February 28 as another winter storm advanced into the area. Eight inches of new snow had accumulated by March 1 at the Idarado Mine which is located along U.S. Highway 550 just north of the summit of Red Mountain Pass. Twelve more inches had fallen by the morning of the 2nd and increased the total depth of snow from 49 to 69 inches.

Accident Summary

Colorado's "Million Dollar Highway" is that stretch of U.S. 550 running from Silverton to Ouray and snaking up to the summit of 11,075-foot Red Mountain Pass. It is perhaps the most scenic and also the most treacherous major roadway in the state. Nearly 60 avalanche paths threaten this 23-mile stretch of highway in winter. Some of these avalanche paths are among the largest in the state and pose an ever-present threat to motorists and workmen clearing the road below.

The first sign of danger from this February 28 storm occurred at 1000 on March 1 when the Blue Point avalanche ran across the highway to a depth of 8 feet. This small avalanche path is located just north of the pass summit and runs with every sizable storm. At 2230 on March 1, two more avalanches ran across the road: Slippery Jim covered the road 10 feet deep; East Riverside, 15 feet deep. The road was now impassable and more unstable snow was hanging above; the highway gates were closed and locked on each side of the pass until the road could be cleared and avalanches controlled with artillery the next morning.

On the morning of March 2, a group of Colorado Highway Department employees began the slow work of clearing the avalanche debris from the highway. The crew was working the East Riverside debris around noon when all but one man left for Ouray to pick up some additional equipment. Robert Miller, age 36 and a father of seven, was left alone working with a D-7 cat under the East Riverside avalanche.

Just a few minutes before noon, the East Riverside avalanche struck again! A large slab of snow broke loose from the starting zone and rumbled down the track. Miller had no chance to escape as the wall of snow hurled him and his machine into the canyon below and buried both under tons of snow.

Rescue

The rest of the work crew was returning from Ouray when they sighted an avalanche dust cloud filling the canyon a few miles ahead. "Oh, God! He's gone," gasped one of the men, realizing that this was the East Riverside avalanche and that Miller was working beneath it. They radioed for help and hurried to the scene; within a short time about 50 men began probing the area. At 1330, the D-7 cat was found under 7 feet of snow. The massive machine had been carried 300 feet across the canyon by the avalanche!

The search for Miller continued without success. At 1530, the probe line was halted by the sheriff because of deteriorating weather and the threat of yet another avalanche. This threat came from both East Riverside and from West Riverside, which lay on the opposite side of the canyon and had not yet run.

The following morning the 75-mm pack howitzer was brought out to fire on the avalanche paths. Both the East and West Riverside slide paths were shot with several rounds without releasing any snow. However, three other slides along the highway were brought down by artillery fire. Because rescue operations were still considered hazardous, no probing of the avalanche area was carried out that day.

On the morning of the 4th, the rescue began again with probe lines and bulldozers to move out some of the deeper snow. Finally at 1630, the body of Robert Miller was found under 4 feet of snow and 120 feet from where his damaged cat lay. His watch had stopped at 1156, the moment of impact of the clubbing avalanche. The body was removed and the rescue was concluded by 1800.

Avalanche Data

The East Riverside avalanche is a particularly dangerous path that produces large slides and runs frequently. Almost 7 years earlier to the day it claimed three other victims (see *The Snowy Torrents* No. 63-2). The slide falls some 3,200 feet vertically down the northwest flank of Abrams Mt., and hits the highway directly. As it crosses the road, the avalanching snow then falls into the gorge below. The avalanche hits the highway six times in a normal winter.

Another factor making East Riverside so dangerous is its habit of running more than once over a short time span. Because of the huge 75-acre catchment basin, even if only a third of the basin avalanches, the road can be hit by a large volume of snow. This still leaves a larger volume hanging above the road —ready to slide at a later time! To further compound this problem, no part of the starting zone is visible from the road below: motorists and highway crews have no visual warning before the snow sweeps across the road.

Both East Riverside avalanches in this report were classified as SS-N-3; the first released from the top left of the catchment basin and the second from the top center. A total of 19 avalanches resulting from this storm were observed along the Million Dollar Highway, but the East Riverside dominated the action as usual.

Comments

Considering the potential severity of the avalanche problem, it is surprising that there have been so few avalanche accidents along Red Mountain Pass. The highway department's policy of closing the highway under extreme conditions is of primary importance here. The policy is made workable by the relatively low volume of traffic along the highway. The artillery control program is also vitally important but still is limited by no provision for blind firing during periods of poor visibility. Optimum use of artillery demands that blind firing be incorporated into the control program.

Even the best control policies, however, cannot completely protect the men who must clear snow from the road. When clearing out avalanche debris they are particularly vulnerable, with no place to go should an avalanche release above them. Even the enclosed cab such as that occupied by Miller is of no help when struck by a large avalanche. A long, heavy avalanche shed is the only sure protection from the East and West Riversides.

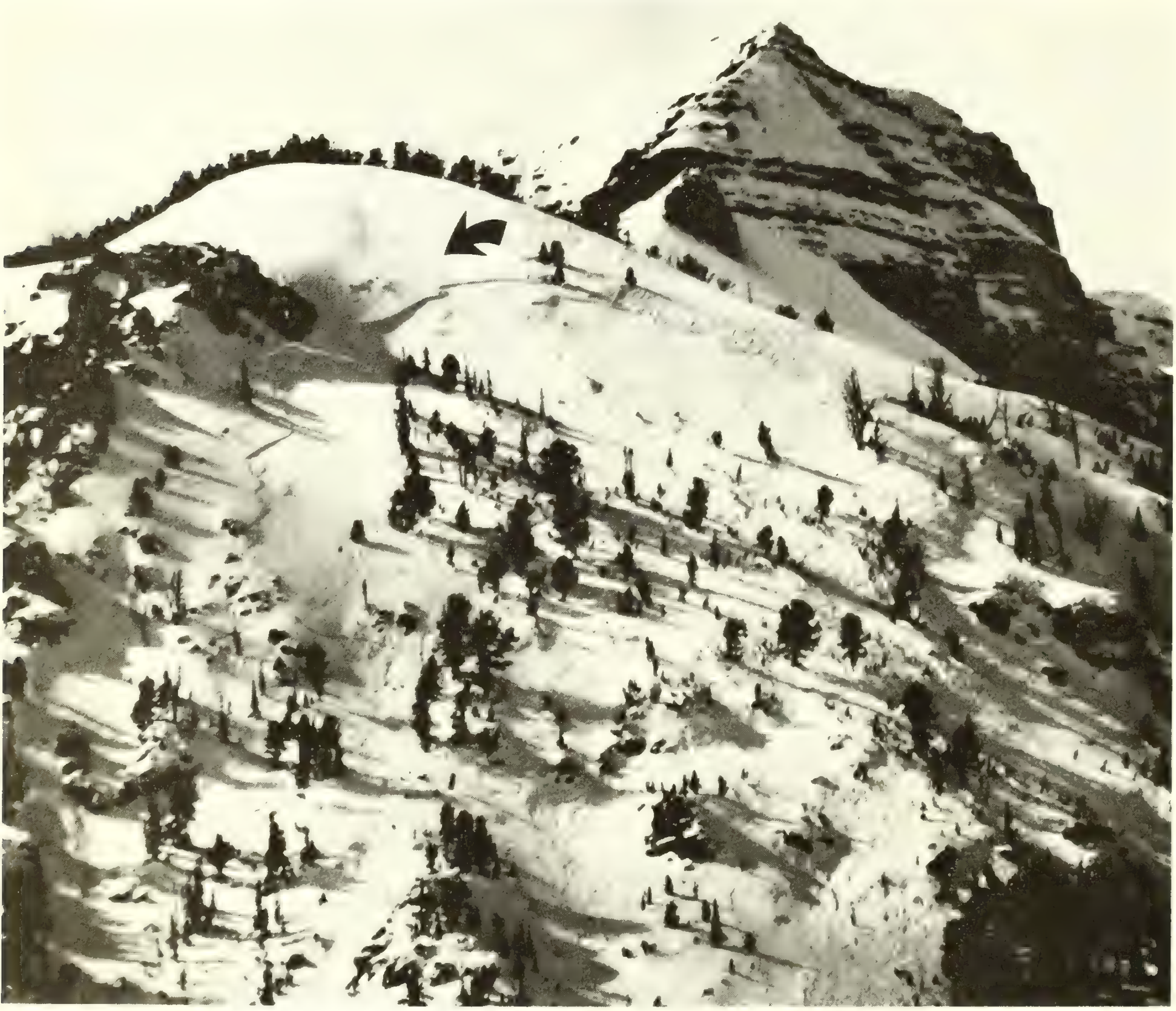
1 caught, partly buried, and injured

Weather Conditions

Overnight, March 27 to 28, 13 inches of snow fell at Jackson Hole Ski Area. This snow fell on a sun crust that had formed during a period of warm sunny weather earlier in the month. On March 30, the weather was clear and cold with northeast winds that averaged up to 31 m.p.h.

Accident Summary

Late on the morning of March 30, a party of five skiers left the patrolled and controlled



No. 70-5. Jackson Hole, Wyoming. The Four Pines touring area. The arrow marks the victim's ski tracks leading into the fracture line.

boundary of the ski area for a ski tour in the Four Pines area. With the group was a Jackson Hole ski patrolman who acted as a guide for the party. The skiers approached Four Pines via the ridge between the Green River and Pinedale bowls. Four of the skiers, including the guide skied into the powder on a timbered north-facing slope. Rich Ream, 52, skied off by himself, however, onto a mostly open, east-facing slope on which a hard wind slab had formed from the strong northeast winds.

At about 1215, Ream skied across the top of Four Pines, did a kick turn, made about five turns down the fall line, then fell. He got up and had made about five more turns when the entire hill fractured 200 feet upslope from him. He was engulfed by the avalanche and carried helplessly on a fast ride through some trees.

The rest of the party did not know the avalanche had run until they saw the debris. They located Ream at about 1230 well down the slide path but on top of the snow. He had been carried down approximately 700 feet vertically and had sustained severe injuries during the ride. A request for a rescue party was quickly sent to the ski area.

Rescue

A hasty rescue party left Rendezvous Peak at 1240 equipped with emergency first aid equipment. This party was followed shortly by a second party of four patrolmen carrying a toboggan. Ream's injuries were severe—facial cuts and broken bones in both arms and both legs. He was taken back to the ski area in the toboggan and then transferred to the hospital in Jackson.

Avalanche Data

This avalanche was a HS-AS-3 that consisted of an unstable new snow layer sliding on a hard snow crust. Although triggered by a single skier, the slab fractured along a broad front and fell 1000 feet in elevation. The Four Pines area is lightly to moderately timbered and is an east- to northeast-facing slope.

Comments

Although ski touring was open at Jackson Hole, it was restricted to groups with guides only. This touring party did have a guide. However, the victim got into trouble when he departed from the group to ski the open slope on which a dangerous wind slab had formed.

3 caught

Weather Conditions

Total snowfall had been normal in the Wasatch for the winter of 1969-1970. April snowfall, however, had been considerably above average assuring a lingering, deep snowpack at high elevations as spring stretched toward summer. Exceptionally warm weather made the weekend of May 16 and 17 excellent for hiking in the mountains. Both days saw the temperature reaching into the upper seventies even at higher elevations. A warm, dry wind blew in from the west across the Great Salt Lake.

Accident Summary

On Sunday, May 17, four young people were picnicking up Big Cottonwood Canyon east of Salt Lake City. They had picked a spot along a stream near the Storm Mt. Picnic Ground and near the mouth of Stairs Gulch.

Around 1500, the four picnickers watched as three hikers walked by and headed toward Stairs Gulch. A short time later the four young people were amazed to see the stream in front of them suddenly stop flowing, quickly being reduced to a mere trickle. Curious, they walked around a huge boulder upstream from their picnic site and saw that an enormous wet-snow avalanche had slid down Stairs Gulch and dammed up the stream. The avalanche had missed the picnickers by little more than 100 feet, piling debris 50 feet deep across the streambed. They quickly remembered the three hikers that had gone into this area only a short time earlier. No sign of the hikers could now be seen anywhere up the canyon. One of the picnickers then hurried to the nearest telephone to alert the Sheriff's office.

Rescue

The Sheriff's Search and Rescue group responded by rounding up a crew of men and sending them to the avalanche area. Probe poles were sent down from Brighton Ski Area, and a total of 17 men began probing the debris. At the same time a check of vehicles at the picnic ground parking lot was established to check for any missing persons in the canyon.

As the probing continued, U.S. Forest Service District Ranger Ames Harrison climbed to the top of Stairs Gulch seeking the missing hikers. At about 1830 while at a safe vantage point at the top of the gulch, Harrison saw the remaining snow in the catchment basin suddenly break loose! He instantly radioed to the rescuers at the bottom that another avalanche was on its way.

The rescuers scattered, some fleeing across the stream and others clawing up the rock sides of the gulch. The wet snow avalanche was not fast moving, and all men made it to safety; three men, however, were caught but not buried by the moving snow.

After this narrow escape, the rescuers regrouped to determine whether anyone was missing. It was ascertained that all the men were accounted for. Meanwhile, the car check had revealed neither unattended cars nor any reports of missing persons in the canyon. In view of the unsafe working conditions, it was decided to suspend the rescue operation unless some evidence turned up indicating that someone might be buried in the avalanche.

No missing persons report was ever filed, and finally when the snow melted out weeks later, no victims were found. Although no one had been buried in the first avalanche, the rescuers did not know this and were forced to search for possible victims. The rescue effort narrowly averted a disaster of its own.

Avalanche Data

Both avalanches running out of Stairs Gulch were classified as WS-N-4. Warm air temperatures and strong solar radiation had greatly weakened the deep snowpack in the starting zone, bringing it to an isothermal state. This finally resulted in failure. The slides were wet, heavy, and slow moving. Both ran about 1½ miles in length, dropped approximately 3,500 feet vertically, were 150 feet in width, and deposited snow about 50 feet in depth in the runout area.

Stairs Gulch is a huge northwest-facing gully that has run even larger in the past. On several occasions it has reached the highway in the bottom of the canyon, a vertical drop of some 4,500 feet. The steepness of the starting zone varies from 35° to 45°, and its bowl-shaped catchment area allows snow to be trapped from all wind directions. All these factors taken together make this a highly erratic and dangerous avalanche path.

Comments

Deep, isothermal snowpacks in late spring are ripe for deep-instability avalanches. It is common for these to run in a piecemeal fashion, increasing the possibility of several avalanches down the same track over a short time interval. Rescuers should be aware of this capricious quirk of avalanches and should always be prepared to make a hasty escape. A timely warning prevented this rescue effort from becoming a tragedy within itself.

This incident vividly emphasizes the importance of a "lookout" for avalanche rescues. Rescues conducted without a specifically posted guard are risky at best.

1 caught, buried, and killed

Weather Conditions

A storm moved in from the Pacific on Saturday, December 26, bringing more snow to the North Cascades. By Sunday morning, 4 inches of snow had fallen at the Mt. Baker Ski Area. The storm continued and dropped 19 additional inches of snow by the afternoon of Monday, December 28. The depth of snow on the ground was approximately 125 inches. Temperature during this period ranged from 20° to 28°F; winds were mostly from the south and averaged up to 17 m.p.h.

Avalanche control was carried out routinely on Sunday the 27th, and eight small soft slabs were released. On Monday morning, 12 small avalanches were released and the ski area was opened by 1030.

Accident Summary

Snow continued to fall and the wind blew throughout the day. At 1515 on the 28th, Rolf Mueller and Klaus Kerstan unloaded from Chair No. 4 and skied for a distance of about 350 feet toward the White Salmon run to the east of the chair; here the two men stopped on a cat track near a tree. Mueller then skied on alone for about another 200 feet before stopping and looking back for Kerstan. Visibility was very bad because of the continuing storm, and the two skiers did not want to get separated.

Mueller saw Kerstan ski away from the tree, but failed to locate him when he looked back a few seconds later. At this time a small avalanche ran over the back of Mueller's skis. However, this appeared to be just a small sluff and he paid it little attention.

He waited a few more minutes and then skied slowly down White Salmon, expecting Kerstan to catch up. Mueller then waited at the bottom of the chair and eventually skied two more runs looking for his friend. When the lift closed, he went to the base area and checked Kerstan's car, the shops, and the bar. Mueller decided that Kerstan was missing, and at 1610 he notified the ski patrol.

Rescue

The patrol questioned Mueller to learn where Kerstan was last seen and on what part of the mountain he could be lost. Mueller said they had been on Shuksan Arm skiing the White Salmon run. It was only after a few minutes of questioning that Mueller mentioned the small avalanche. At this time another patrolman came in from sweep and confirmed that a small slide had run over the cat track on White Salmon. Snow Ranger Mike Dolfay was notified and a hasty search was organized.

At 1740 the first search party of eight men arrived at the slide area equipped with probes, shovels, and flashlights. The continuing snowfall and wind had obscured the surface of the slide making the boundaries and extent of the debris indefinite. The rescuers systematically probed the debris covering the cat track and finished at 2045 with negative results.

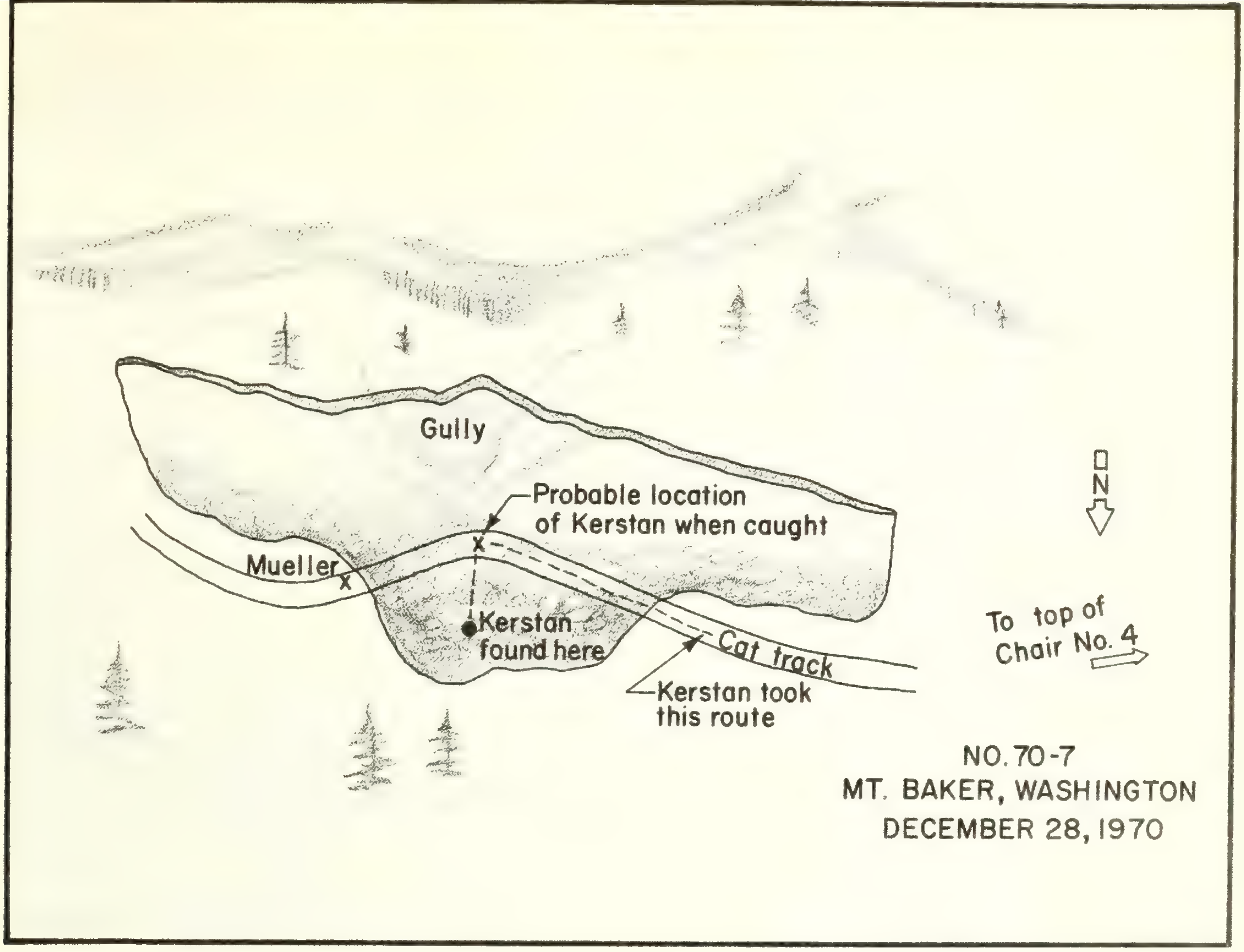
The rescue party returned to the base area and made preparations for another search effort that included a snow cat equipped with a front-end blade to remove some debris for easier probing. This party reached the slide area and began work at 2340. At midnight the body of Kerstan was struck with a probe pole about 30 feet below the road and under 6 feet of snow.

It took some time to shovel down through the hard snow, but after 10 minutes of hard work the body was uncovered. Kerstan was found face down in a prone position without any signs of life. He was taken to the base area in a toboggan where a doctor pronounced him dead. It was felt he had died very quickly of suffocation, probably within 5 or 10 minutes after being buried.

Avalanche Data

This small avalanche was classified as a HS-N-1 running about 140 feet slope distance and 50 feet vertically. The fracture line was 2½ to 3 feet deep and extended a length of 200 feet. The slide occurred on the north side of Shuksan Arm at an elevation of 4,800 feet.

The terrain in this part of Shuksan Arm is



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typically benchy with numerous rolls and gullies. The avalanche was centered in a small gully that did not have a past history of sliding. The steepness of the starting zone varied greatly—35° to 24°—because of the rolling terrain. However, the slope was undercut by the cat track which removed support from below. The unstable slab fractured under the added stress of the new snow accumulation during the previous 36 hours. Wind had increased new snow deposition to about 36 inches in the small gully.

Comments

Normally an avalanche of this size would fall in the category of a harmless bank sluff. But fate intervened in this case and placed the victim, who was traversing the cat track, directly under the slab at the moment of release. He was carried into the shallow gully, and the volume of snow was sufficient to bury him deep enough to snuff out his chance of survival. This accident is another example of a small avalanche becoming a killer (see also *The Snowy Torrents* Nos. 62-7 and 64-11).

This type of benchy terrain makes effective avalanche control difficult. There are innumerable small pockets to trap blowing snow. During storm periods, hazard can build up quickly after avalanche control has been completed in the morning. This is the kind of situation that requires continuous checking during the day to prevent serious slab conditions from forming. When such conditions are suspected, there should be no hesitancy to close the area to skiing until control measures minimize the hazard.

1 caught, buried, and killed

Weather Conditions

A major snowstorm moved into the Sierras on December 16 dumping up to 60 inches on the ski slopes around Lake Tahoe by the 22nd. The snowpack had reached a depth of about 60 inches in the Alum Creek area. This region lies at the 7,600-foot elevation on the eastern flank of the Sierras and is about 4 miles southwest of the suburbs of Reno.

Another storm began on December 26 bringing snow and strong southwest winds of 30 to 45 m.p.h. The Reno airport was temporarily closed by this storm on the 27th. This storm continued on the 28th with snow, strong wind, and a temperature of 20°F.

Accident Summary

At 2100 on December 28, a party of four men on four snowmobiles left Skyline Blvd. in southwest Reno for an evening of snowmobiling. In spite of the near-blizzard weather conditions, the group headed for steeper terrain, up the Hunter Lake jeep road. They followed the road for about 5½ miles until coming to a steep slope above Alum Creek where the road begins to switchback. The men abandoned the road at this point and attempted to climb directly up the slope, but it proved to be too steep. They then began a traverse across the slope in an attempt to gain altitude.

Each machine cut a separate path across the slope with David Woodward lowest of the four. While midway onto the slope one of the drivers glimpsed a running avalanche illuminated by the headlight of his machine. He could also see Woodward's headlight lower on the hillside directly below the avalanche. This headlight was visible for a short time, and then it went out! The time was 2245.

The three other drivers had not been involved in the avalanche and immediately went downhill to check on Woodward. His track was plainly visible leading into the slide, but there was no track leading out. The men scuffed the surface of the debris but could find no sign of Woodward or his machine. While two men stayed to search, the third, Marvin McKinney, headed back down the Hunter Lake road to summon help.

Rescue

McKinney arrived at the fire station on Skyline Blvd. at 2347 and reported the accident to the Washoe County Sheriff's Department. The Washoe County Jeep Squadron was alerted and, in turn, the Reno Sno-Drifters Rescue Group was notified. The Sno-Drifters were a section of a local snowmobile club who had received first aid and rescue training.

At 0022 on the morning of December 29, Sgt. Glen Vogler of the Sheriff's Department arrived at the fire station and assumed leadership of the rescue group. He had participated in numerous other search missions, but this was his first avalanche rescue mission, and he had received no training in avalanche hazard or search techniques.

At 0115, McKinney led men with snowmobiles toward the accident site. A second party of eight more rescuers left the fire station 10 minutes later. By 0230 there were 23 men at the accident scene to help the two men who had been searching in vain for their lost companion. Almost 4 hours had passed since Woodward had been buried, giving him little chance of survival. Tom Newton, the head of the Reno Sno-Drifters, assumed leadership of the rescue at this time.

The rescuers were working under hazardous conditions. Strong winds were producing near-blizzard conditions, and a considerable amount of snow was still hanging on the slope above. In addition, the men were very poorly equipped for an avalanche rescue; they had only two probe poles among them. Nonetheless, an organized search was initiated near the toe of the slide and proceeded across the slope toward the victim's entry track. Progress was very slow because of the lack of probes. After a few minutes, Newton decided to abandon this procedure for a more random but more rapid search. The debris had set up such that walking on the snow was easy but probing into it was very difficult, especially without standard avalanche probes.

At 0258 a runner of the buried snowmobile was struck under 6 inches of snow near a stand of aspen trees. Frantic digging uncovered the machine upside down. Woodard was uncovered beneath and to the side of the machine under 4 feet of snow. His foot was pinned between the snowmobile and a tree; there were signs that he had struggled to get free. Although body warmth was still present, there were no other indications of life. Artificial resuscitation and external heart massage produced no response from the victim.

A snow cat had been brought to the accident scene and was used to carry the victim back to the Skyline Blvd. fire station. A doctor pronounced him dead at 0554. All rescuers and equipment left the accident site a short time later, concluding the rescue operation.

Avalanche Data

This was a medium-size hard-slab avalanche triggered by a snowmobile traversing the slope. All or any one of the four machines crossing the slope on different tracks may have triggered the slide. The slab broke beneath a small cornice at the top of the slope. The slide was about 250 feet in both width and length; it dropped some 120 feet vertically.

This north-facing slope is very steep —about 45°—near the top where the avalanche released and flattens to 25° to 30° farther downhill. The top of the slope lies at an elevation of 7,600 feet with a cornice forming at the ridge and the steep lee slope providing an excellent catchment zone. The strong southwest winds swept across the flatter windward slope and redeposited the snow on the steep north slope. The resulting hard-slab avalanche left table-size blocks of snow at the foot of the slope.

Comments

This accident marks the second avalanche fatality to a snowmobiler; the first is documented in No. 68-7. (A third fatality occurred in January 1971. See No. 71-7) The thought of avalanche apparently had not entered the minds of these four snowmobilers. The sum of their errors led to tragedy.

First, the men exercised poor judgment in touring in steep terrain during a raging snowstorm. Going at night compounded this error. The combination of heavy snowfall and forceful winds had created very high avalanche hazard. Storm periods are the most dangerous while touring in avalanche terrain: more than 80 percent of all avalanches fall during or immediately after storms.

Second, they crossed the slope in an unsafe manner. The group should have crossed one at a time following the same track rather than all crossing at once and each taking a separate path.

Third, the men were unprepared in the event of emergency; they had no rescue equipment of their own. On any back-country tour, it must be realized that the survival of a buried avalanche victim rests solely with his companions. Additional help is too far away to allow a live rescue. In this case, collapsible probe poles and a shovel or two may have resulted in a saved life.

Finally, this accident points out the need of avalanche training for snowmobile touring groups and for anyone who might be involved in an avalanche rescue. Knowing the danger signs would have kept this group at home, knowing the safe traveling procedure would have minimized the chance of triggering the avalanche, and having emergency rescue equipment would have given the buried victim a much better chance. The rescuers, too, were inadequately prepared for their mission. They had neither adequate rescue equipment nor adequate training. To remedy these deficiencies, club leaders should initiate education programs of literature, films, and guest speakers with emphasis on avalanche safety and rescue.

2 caught and buried

Weather Conditions

A major snowstorm began at Crystal Mountain Ski Area on the evening of December 27. Snow fell continuously over the next several days; by the morning of December 30 a total of 36 inches of snow had been recorded. Heavy snow fell and strong winds, mostly westerly, blew on Wednesday the 30th. The upper mountain was closed because of high winds; all lifts were operating on the lower mountain.

Accident Summary

At about 1015 on the 30th, four young skiers caught the Quicksilver chairlift from the base area and rode to the top. They left the chairlift and skied to the left (east) toward an area called Boondoggle. This is mostly an intermediate area with skiing in the trees and on a partially cleared ski run. Above this run is a very steep, north-facing slope that is the Boondoggle avalanche path. This path is skied and runs infrequently.

The four skiers traversed onto this slope at a transition below the very steep upper section. Two of them skied downhill a short distance and then stopped to wait for the other two. Beth Johnson, 16, and Brian Berksted, 13, were still up on the slope; Brian was having trouble with his ski binding. On Brian's second fall, an avalanche released on the steep portion of the slope 200 feet above the two skiers. They were hit by the toe of the fast moving slide and were tumbled downhill for 10 or 12 feet and buried.

Both Beth and Brian were completely but only shallowly buried. Both were able to clear the snow away from their faces and then dig themselves out.

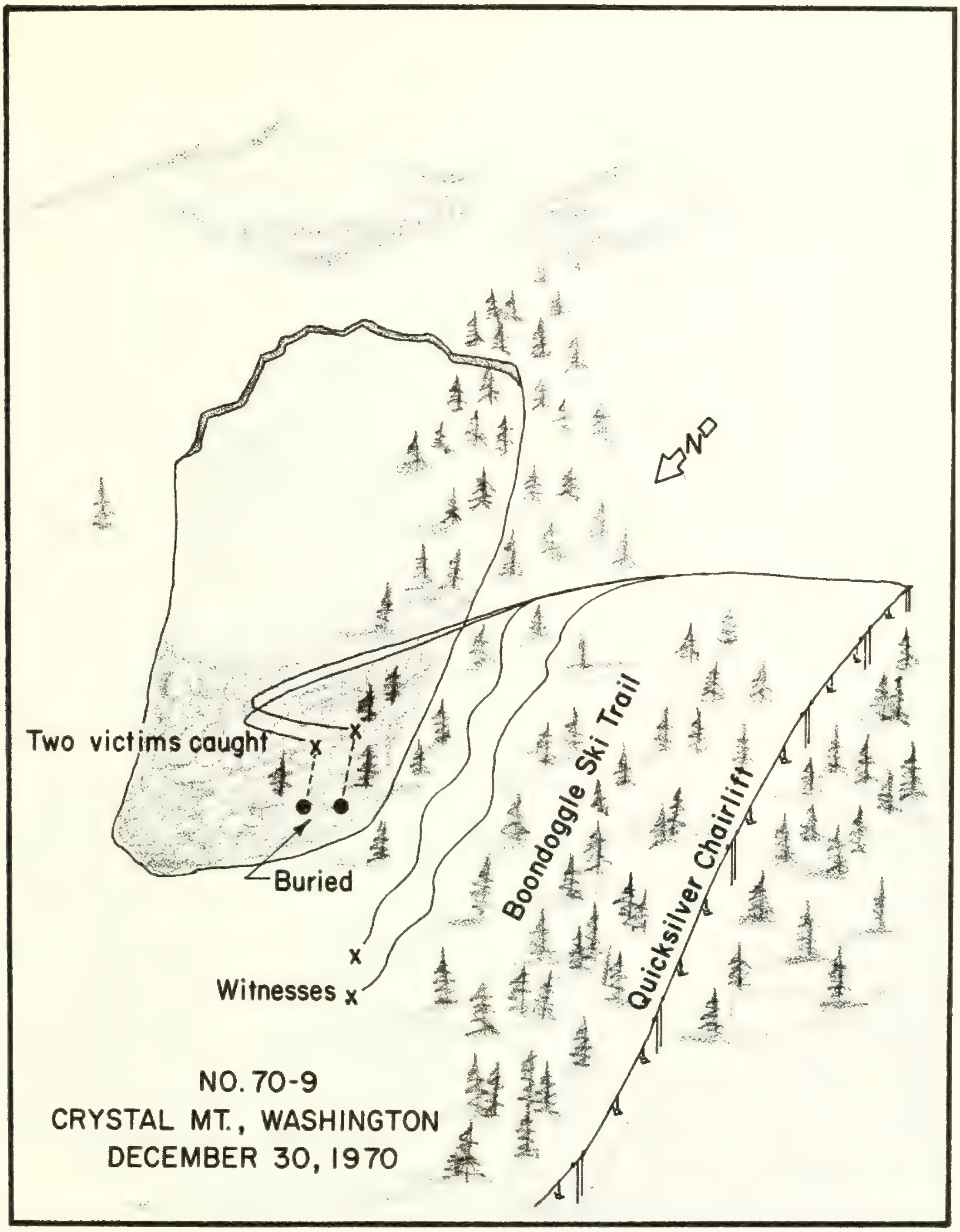
Their two companions who were waiting below had watched as all this happened. However, because of bad visibility they were unsure of what they saw. At first they thought the two skiers were being obscured by snow blowing off the trees, but soon realized it had been an avalanche. They walked back uphill to help their stricken companions. Brian had lost a ski in the slide; a search by the four skiers failed to find it. They then skied to the base area to report the accident to the patrol.

Avalanche Data

This avalanche was classified as SS-AS-2, fracturing 3 feet deep and running some 200 feet down the slope. The Boondoggle avalanche path is north-facing and portions of its starting zone are very steep—in excess of 40°. It runs infrequently, mainly because of heavy timber in the starting zone, and had not been controlled on the morning of December 30. This is normally considered a safe skiing area.

Comments

The two victims of this accident were struck by only the toe of the avalanche. This explains their being carried only a very short distance and their shallow burial. Following this accident, the area has been checked more closely for signs of instability. To insure safety, low-frequency avalanche paths in ski areas should receive the same attention as frequent ones.


N
Two victims caught
x
x
Buried
Witnesses
x
x
Boondoggle Ski Trail
Quicksilver Chairlift
NO. 70-9
CRYSTAL MT., WASHINGTON
DECEMBER 30, 1970

2 caught, 1 partly buried

Weather Conditions

Fifty-six inches of snow covered the ski slopes at Breckenridge on January 9; this included 9 inches of fresh powder from a recent storm. Preceding this storm, temperatures had been exceedingly cold, falling as low as −29°F on the morning of January 6. On Sunday the 10th, moderate but gusty winds were moving snow on the upper slopes and the temperature was 20°F. From the 5th to the 10th, wind direction was continually from the northwest. Avalanche control that morning had released one deep slide; thus, the uncontrolled slopes outside the ski area were considered unstable and touring was not recommended.

Accident Summary

By late morning on the 10th, all the powder snow at Breckenridge had been skied out. A group of seven skiers decided to head outside the ski area to find some untracked snow. They skied by the patrol building and inquired from two volunteer patrolmen who were standing outside whether an area called Cucumber was open. They were told it was and headed off.

Cucumber is located north of and beyond the ski area boundary and lies at the extreme northeast end of a wide bowl named Horseshoe Bowl. Avalanche control work is seldom performed in this area. Avalanche closure signs were posted on the normal route to Cucumber, but on this day the group chose a much higher route out of the ski area. Because their climb and high traverse bypassed the closure signs, the group unknowingly entered a closed area.

When they reached the first powder-filled gully, two of the skiers couldn't resist the temptation and jumped into it and skied it to the bottom. The remaining five—Eric Bell, Jim Hintschel, Mike Allen, Jim Wallace, and David Greer—continued toward Cucumber. Upon reaching their destination, four members of the group began hiking up toward the ridge crest while Greer skied down alone and waited at the bottom of Cucumber.

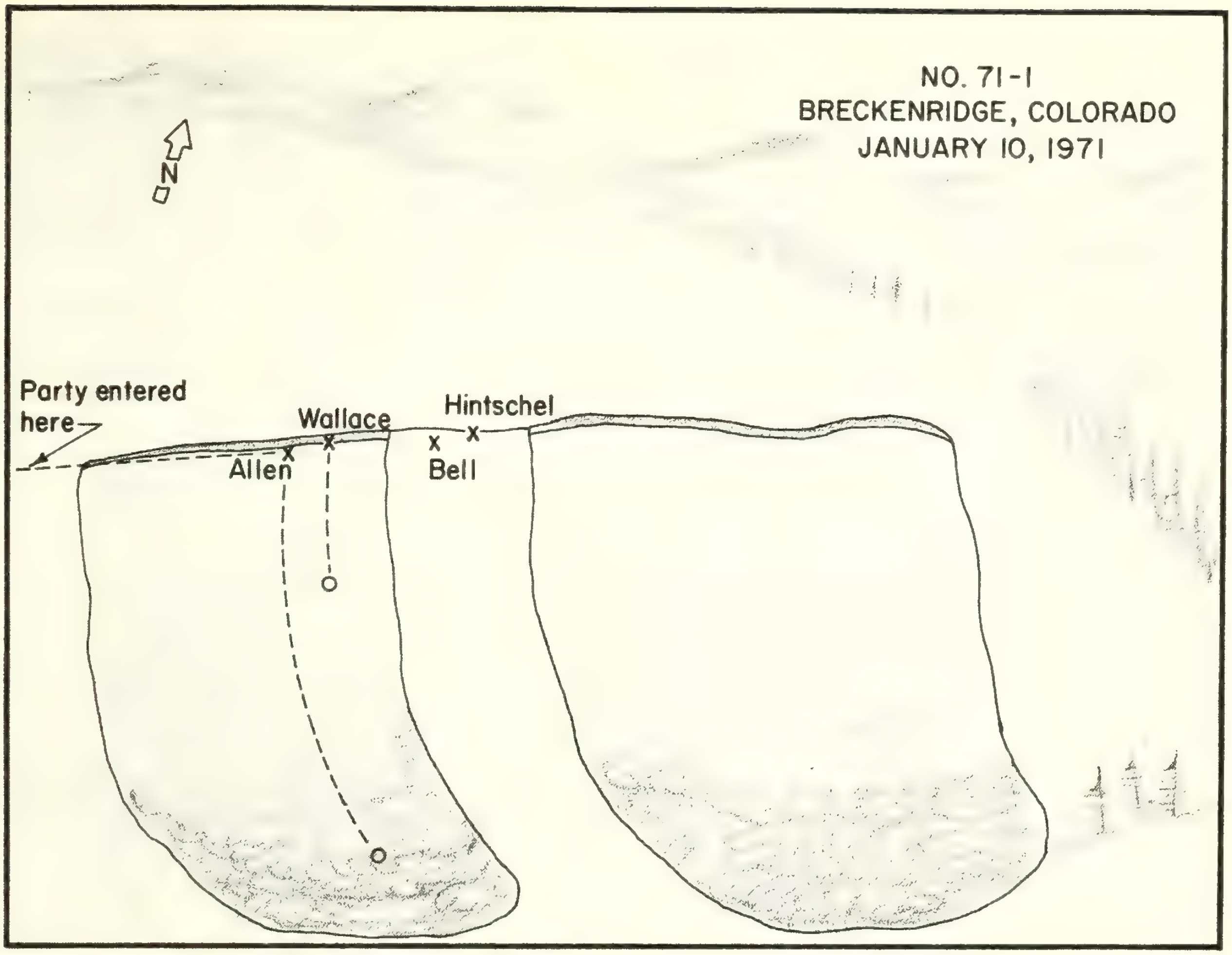
The four skiers began their traverse up and across a broad, open snowfield. Hintschel was in the lead and highest on the slope, Bell was slightly behind and below Hintschel, and another 10 feet behind and 15 feet below were Allen and Wallace. Suddenly the slope broke beneath their skis in a deep fracture with a muffled "whoomp" sound! Two sections of the slope began sliding away with one section catching Allen and Wallace. Between the two avalanching areas, a 50-foot-wide strip of snow fractured but did not slide. Hintschel and Bell were standing on this strip of the slab; the avalanche ran both in front of and behind them.

Wallace was standing right on the 4-foot-deep fracture line and fell into the void as the slab slid away. He slid down the bed surface about 80 feet before coming to rest on top of the uppermost debris. Allen, who was slightly lower than Wallace, was caught by the moving snow and swept 300 feet downhill; he was buried to the waist when the avalanche stopped. Wallace skied down the debris and helped dig out Allen.

Meanwhile, Hintschel and Bell were left standing on the part of the slope that did not avalanche. They were afraid to move and stood very still for fear of triggering the slab. The crack in the snow ranged from 2 to 10 feet uphill from their positions. As they waited, they could see that it was slowly widening. The two men talked over their situation and finally decided that Bell should ski straight down. He did so and reached flatter terrain where he was out of danger. Hintschel was left on the slope; he slowly worked his way to the edge of the slab, finally stepping to safety on the hard bed surface of the avalanche. The crack in the slab had widened to 6 inches by the time he got off.

Rescue

Around lunch time, two pro patrolmen skiing within the ski area saw two fresh avalanches in the Cucumber area. They made a short hike to view the slides better and then saw some skiers in the area, two of them stand-



ing on a small strip of snow between the two avalanches. The patrolmen radioed headquarters and alerted them to prepare for a rescue; then the two men skied toward the accident site. When they got there, they found that everyone was accounted for and that Allen, the partly buried victim, was all right. The organized rescue was called off.

Avalanche Data

This avalanche, classified as a SS-AS- 3, was triggered by the weight of the four skiers. The fracture line averaged 4 feet in depth and was 600 to 700 feet in length. Although the fracture line was continuous, the avalanche was split into two parts, leaving a 50-foot-wide strip of snow on the mountainside. The western half of the avalanche, the part that caught the two skiers, was about 200 feet wide; the eastern half, about 400 feet. Both slides ran more than 300 feet down the slope. The center section of snow fractured and settled but was more securely anchored and did not avalanche.

Cucumber is a south-facing slope on the northern part of Horseshoe Bowl. The northwest winds of the 5 previous days had heavily loaded the slope. This slope of about 33° is not particulary steep and does not slide very often. However, in this case, in spite of its southern exposure, very cold temperatures had minimized settlement in the freshly deposited snow. The slab was highly unstable as evidenced by the depth and length of the fracture line. This was the first time this seldom-skied slope had avalanched this winter.

Comments

This accident might have been prevented with a little extra effort from both the ski area and the skiers. The problem partly arose because the volunteer patrolmen reported the area open when in fact it was closed due to avalanche danger. Better communication between the pro patrol and the volunteers would have eliminated this piece of misinformation. Also an extension of the avalanche danger signs would have been seen and most likely heeded by these adventuresome skiers.

But a great share of the blame must remain with the skiers themselves. The party made no attempt to inquire about avalanche conditions; a check with the pro patrol would have revealed that Cucumber was considered dangerous and was closed. It can only be assumed that this party never considered the possibility of avalanches. Continued efforts toward skier education seem to be the key to such accidents.

No. 71-2 Juneau, Alaska January 10, 1971

1 caught, buried, and killed

Accident Summary

Few details are available on this accident that occurred near Juneau on January 10. Greg Oxley, a young climber from Juneau, was climbing on Mt. Juneau above the city. Snow depths on the mountain ranged from 2 to 12 feet.

At about 1530, Oxley was climbing alone in an avalanche area called the Behrends Avenue avalanche, so named because it threatens residents of Juneau living on Behrends Avenue. Wearing campons, he was near the 2,700-foot elevation when he released a large avalanche which buried him under tons of snow. The slide was witnessed by several other persons, and a hasty search was organized. Probing was futile as the debris was 40 to 50 feet in depth. Oxley's body was not found until the following summer when it was uncovered by a bear near the 400-foot elevation.

Comments

A critique of this accident is not possible due to lack of details. It is sufficient to say that one of the hazards of winter mountaineering is avalanches, and these will continue to claim their victims.

It is known, however, that the fatal avalanche was the fourth to run down the Behrends Avenue path on this day. All four were large avalanches which threw up billowing dust clouds. The cause of this remarkable avalanche activity was a local wind phenomenon known as the Taku wind.

The Taku wind is a cold northeast katabatic wind which blows off the inland glaciers and is accelerated to incredible speeds: the wind screams over the ridgetops above Juneau at estimated speeds of more than 200 m.p.h. The avalanche starting zones are quickly loaded so that frequent and large avalanches are not uncommon when the Taku is blowing.

3 houses and numerous miscellaneous facilities damaged

Weather Conditions

The Wasatch Mountains of northern Utah were covered by a deep snowpack by January 1971. Extremely cold air invaded the region in early January, causing temperatures to fall to −22°F and colder. But on January 9 a rapid warming trend began with highs reaching into the midforties at Logan. Temperatures remained mild for mid-January even as a new storm moved into the region on the 11th. By the 14th, Logan had received 14 inches of new snow and higher amounts had fallen in the mountains east of the city. A heavy snow cover blanketed the steep walls of Logan Canyon just east of Logan. U.S. Highway 89 follows the Logan River along the bottom of the narrow canyon where numerous homes, buildings, and other facilities have been built.

Accident Summary

At 1830 on January 13, a large avalanche broke loose from the mountainside above the DeWitt Springs area in Logan Canyon. In the avalanche's path lay the city of Logan water works, the U.S. Forest Service Malibu Campground, and the highway. The water works was hit hardest by the avalanche. The building covering the springs was totally demolished as was the heavy fence surrounding the facility. Electrical power lines to the plant were also destroyed. The damage interrupted water service to Logan, forcing a switch to auxiliary sources.

The avalanche also struck a portion of the campground where it damaged facilities and destroyed trees and vegetation. The slide then continued toward the highway and ripped out 800 feet of telephone line. A car on the highway was struck a glancing blow and narrowly escaped disaster as the avalanche ran across the highway. Two hundred feet of guardrail was mangled as the avalanche covered the highway for 1000 feet in length and up to 25 feet in depth. The road was not cleared until 24 hours later.

On the following day, January 14, a large avalanche released above the Beirdneau summer home development area where a number of homes had been built. The avalanche came down Beirdneau Canyon and reached the northern edge of the residence area. Two unoccupied homes lay directly in the path of the avalanche and were totally demolished. These homes, one a two-story structure, were both of wood construction and stood little chance against the force of the avalanche. A third house also built of wood, was hit a partial blow and suffered lesser damage. Two more avalanches released later the same day from side canyons and followed the same path as the first. Neither of these did any further damage; however, two deer killed by the avalanche were found in the debris.

Also on the 14th, an avalanche slid down Powder Hollow and struck a U.S. Forest Service powder cache. The cache was demolished and explosives were scattered over the snow.

Avalanche Data

Each of these destructive avalanches reached the canyon floor as a wet-snow avalanche. It is not known, however, whether they were wet slabs or hard slabs at the point of release. In any event, they ranged from medium to large and moved a considerable amount of snow down their tracks. All of these avalanches slide only infrequently.

The DeWitt Springs avalanche released at about the 7,000-foot elevation and stopped near the 5,000-foot level after traveling a distance of approximately 1 mile. The Beirdneau Canyon avalanche fractured at an elevation of nearly 8,000 feet and ran a distance of 1½ miles, stopping at the 5,200-foot level. Three separate slides came down the walls of this canyon, the first one doing the damage. The Powder Hollow avalanche was channeled down a narrow ravine and hit the powder cache when the snow spread out at the mouth of the ravine. A similar avalanche in 1965 narrowly missed this same cache.

Comments

These avalanche damage incidents present a good case for avalanche mapping and zoning. The low frequency of these slides adds to their danger in a subtle way: there is a tendency to treat them lightly and not give proper respect to their potential. This results in building permanent structures in avalanche paths where there is near-certainty that such structuers will eventually be damaged or destroyed. Some mountain communities (for example: Ketchum, Idaho) have had the foresight to enact avalanche zoning ordinances.

Damage to the water works facility was estimated at $10,000, and damage to the campground, telephone lines, and highway added several thousand more. The water works could conceivably be protected by an avalanche diversion structure installed uphill of the facility. The building itself should be reconstructed with stronger materials.

The two destroyed summer homes had stood on the land for many years without incident; one was built in 1957 and the other in 1963. But the inevitable happened when a very large avalanche released in the canyon. The total value of the two demolished homes was $22,000, and the lots they occupied were valued at $2,850 each. The third house sustained $1,000 in damages. Following this accident, the Forest Service recommended that no reconstruction of homes be allowed in this area.

The powder cache in Powder Hollow was rebuilt in an area safe from avalanches.

2 caught; 1 partly buried and 1 buried; 1 killed; 2 vehicles buried

Weather Conditions

The Pacific Northwest was on its way to a record snowfall season during the winter of 1970-71. By January 15, Paradise at Mount Rainier had already received 433 inches of snow for the winter and the depth of snow on the ground stood at 176 inches. Avalanches in the Cascades were falling in record numbers, prompting the Weather Service to issue avalanche alerts during the most intense storms.

Snow began falling over the Cascades on January 8 as a major and prolonged storm set in. By the morning of the 14th, Alpental, near the summit of Snoqualmie Pass, had recorded a total of 37 inches of snow containing 2.63 inches of water. But on the 14th, snowfall intensity increased markedly to an inch an hour for much of the next 24 hours. Precipitation intensity exceeded 0.10 inch per hour for most of the next 18 hours. An avalanche warning had been issued by the Weather Service and was in effect for all mountain passes.

Accident Summary

Interstate 90, winding over 3,004-foot Snoqualmie Pass, is the major cross-mountain link between Seattle and points east. Avalanches threaten the highway on both sides of the pass. Two avalanche sheds, one on each side of the pass, were built beneath the paths that avalanched most frequently. However, these sheds cover only the two inside lanes of the interstate; the outside lanes remain uncovered. The east-side snowshed lies 6 miles east of the Snoqualmie Pass summit, and the eastbound lanes are exposed to avalanches running over the roof of the shed. A very large avalanche could conceivably carry a car off the highway and into Keechelus Lake.

At 2315 on January 14, a westbound motorist on I-90 reported a small avalanche had overrun the east snowshed and had caught a car in one of the eastbound lanes. A highway department employee drove to the shed and picked up the stranded driver, Tom Taylor. To prevent eastbound traffic from entering the slide area, they posted themselves on the highway ahead of the slide area. The highway foreman then arrived and asked Taylor what he wanted to do about his car. He said that he would like a wrecker to pull him out so he could be on his way. The wrecker was called at 2346. Snow continued to fall hard.

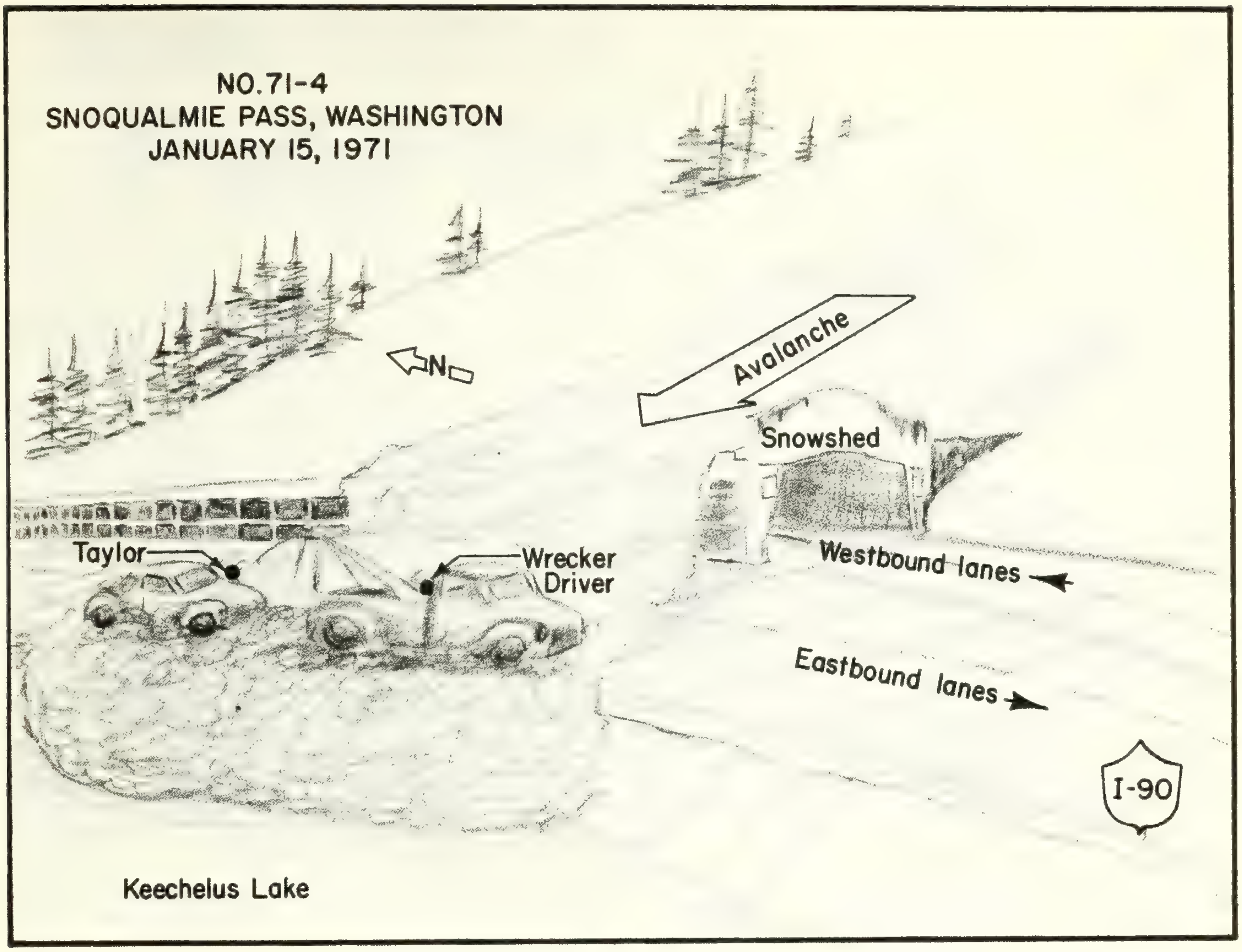
In the meantime, two snow blowers arrived to clear the snow from the highway. The state patrol had arrived and was directing traffic when the wrecker arrived. The wrecker hooked up to Taylor's car and pulled it free of the snow. The wrecker with Taylor's car in tow then pulled forward some 20 to 30 feet and stopped—still beneath the avalanche path.

The time was 0020 in the morning of the 15th when the wrecker driver unhooked the car and both men prepared to drive away. At that moment, another avalanche released on the mountainside above and came hurtling over the snowshed. The two men had only an instant to react; the wrecker driver dove under the wrecker and Taylor tried to get inside his car. Then the avalanche struck, totally burying Taylor and his car. The wrecker was only partly buried, but the driver could not be seen beneath it.

Rescue

After the avalanche stopped, there were four men—three highway department personnel and one state patrolman—immediately on hand to initiate the rescue. They began digging by hand under the partially buried wrecker and found the driver. He was completely buried except for his face and hands which were fortuitously sticking out of the snow beneath his truck. The driver was dug out at 0030 and all efforts were turned toward finding Taylor.

According to the wrecker driver, Taylor's car was sitting close behind the wrecker when the slide engulfed everything. The wrecker was moved out of the way and a snow blower and front-end loader were brought in quickly to locate the car. The car was found within minutes by the snow blower, and the rescuers then began tunneling in with shovels.



At 0120, Taylor was found wedged between his car and the open left door. The snow was tightly compacted around him. Although revival efforts were tried, he was dead from suffocation. Buried for 1 hour, the victim had no chance finding enough air beneath the dense debris. Because of the danger of a third slide (which in fact occurred), the car was not removed until daylight.

Avalanche Data

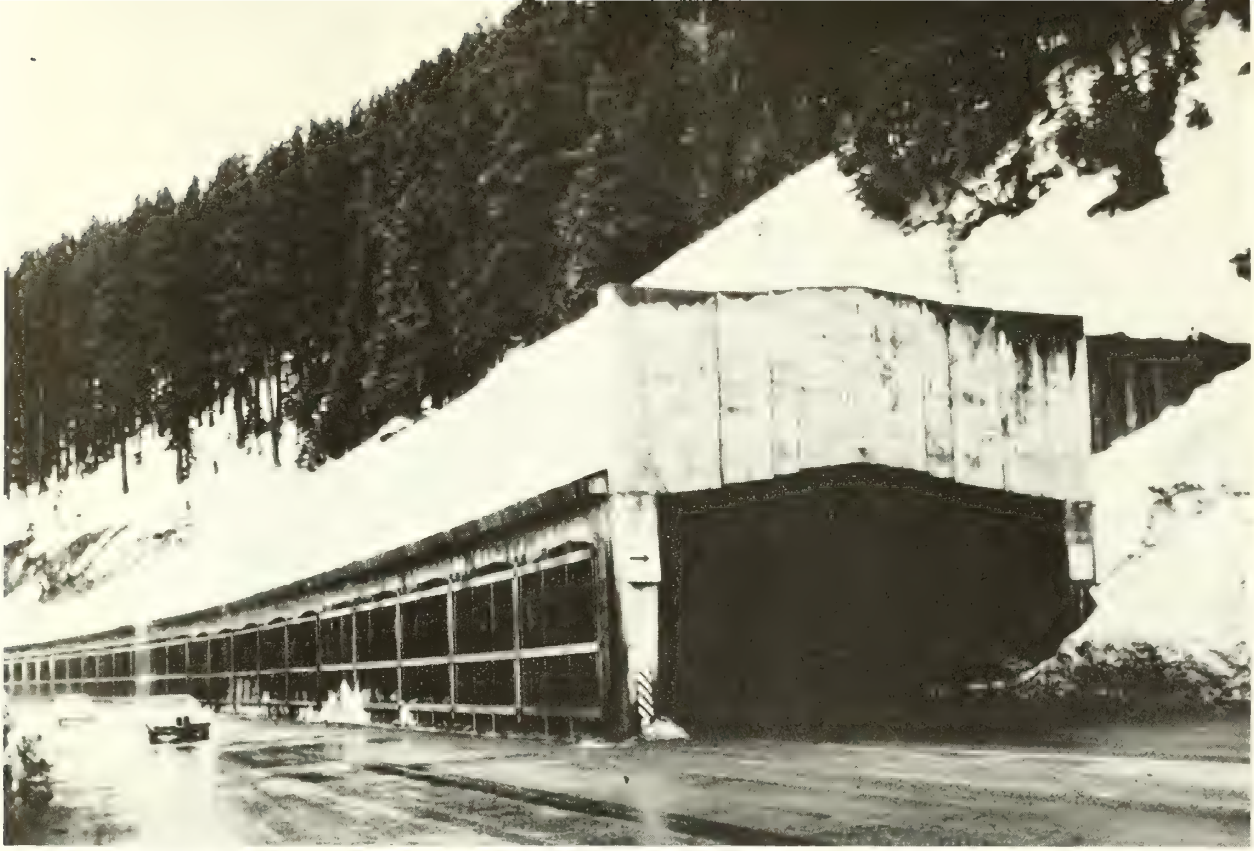
Two avalanches ran down this path in about 1 hour's time. The first was a SS-N-2 and trapped Taylor's car on the highway; the second was a SS-N-4 and deposited snow 10 feet deep on the highway. Both slides were reacting to an intense current snowfall. The second and larger slide ran a distance of 1500 feet, was 300 feet wide, and easily overran the snowshed, cascading onto the highway.

The slope on which these avalanches ran is west-facing and has a steepness of 45° in the starting zone. The path is lightly timbered and avalanches frequently.

Comments

The east-snowshed avalanche on Snoqualmie Pass has a particularly infamous history of burying eastbound traffic on I-90. An earlier accident occurred here in 1966 (see *The Snowy Torrents* No. 66-2) and another in March 1972. Because the snowshed covers only the inside lanes of the highway, fully 50 percent of the I-90 motorists have no protection from this frequent-running avalanche.

This accident is also one more example of the danger of avalanche paths that strike twice in a short period of time. Accidents of this nature are common, as exemplified by Nos. 69-16, 70-4, 70-6, and 71-10. Rescuers should take heed and plan accordingly: spend only as much time as is needed working beneath the avalanche and no more; and post an avalanche guard when feasible.



No. 71-4. Snoqualmie Pass, Washington. I-90 snowshed 6 miles east of the summit of Snoqualmie Pass. The avalanche flowed over the roof of the shed and covered the unprotected eastbound lanes of the highway.

No. 71-5 Crystal Mt., Washington January 16, 1971

3 caught; 1 buried and injured

Weather Conditions

From January 9 to 15, 63 inches of snow were recorded at Crystal Mountain Ski Area, increasing the total snow depth to 91 inches. On the 15th, a warming trend set in and light rain began falling at elevations of 6,000 feet and lower. With the rain came intense west winds averaging 40 m.p.h. and gusting as high as 94 m.p.h. The combination of snow, rain, and wind increased the avalanche hazard to high levels.

Avalanche control was carried out daily in the ski area with little results until the 15th. On that day, class 3 and 4 avalanches began to occur, some running naturally. Friday the 15th was very windy, too windy to run Chair No. 2 which would carry the control teams to the top of the mountain. The lower 75-mm rifle was fired blind, but most of the results went unobserved because of heavy fog and clouds. One large avalanche was heard as it snapped trees on its descent down Exterminator. Only part of the ski area was opened on the 15th.

Accident Summary

Saturday morning, January 16, dawned clear with considerably less wind. At daybreak, avalanche control began in earnest. Snow Ranger Lloyd McGahuey describes the day's activities and the accident in the following narrative.

"At 0600, my assistant Ray Baker and I left for the mountain. There we met members of the Crystal Mountain pro patrol along with two volunteer patrolmen. We discussed the plan of action which was to control Exterminator and Snake Pit before opening Chair No. 1. Ray and I fired the midway rifle.

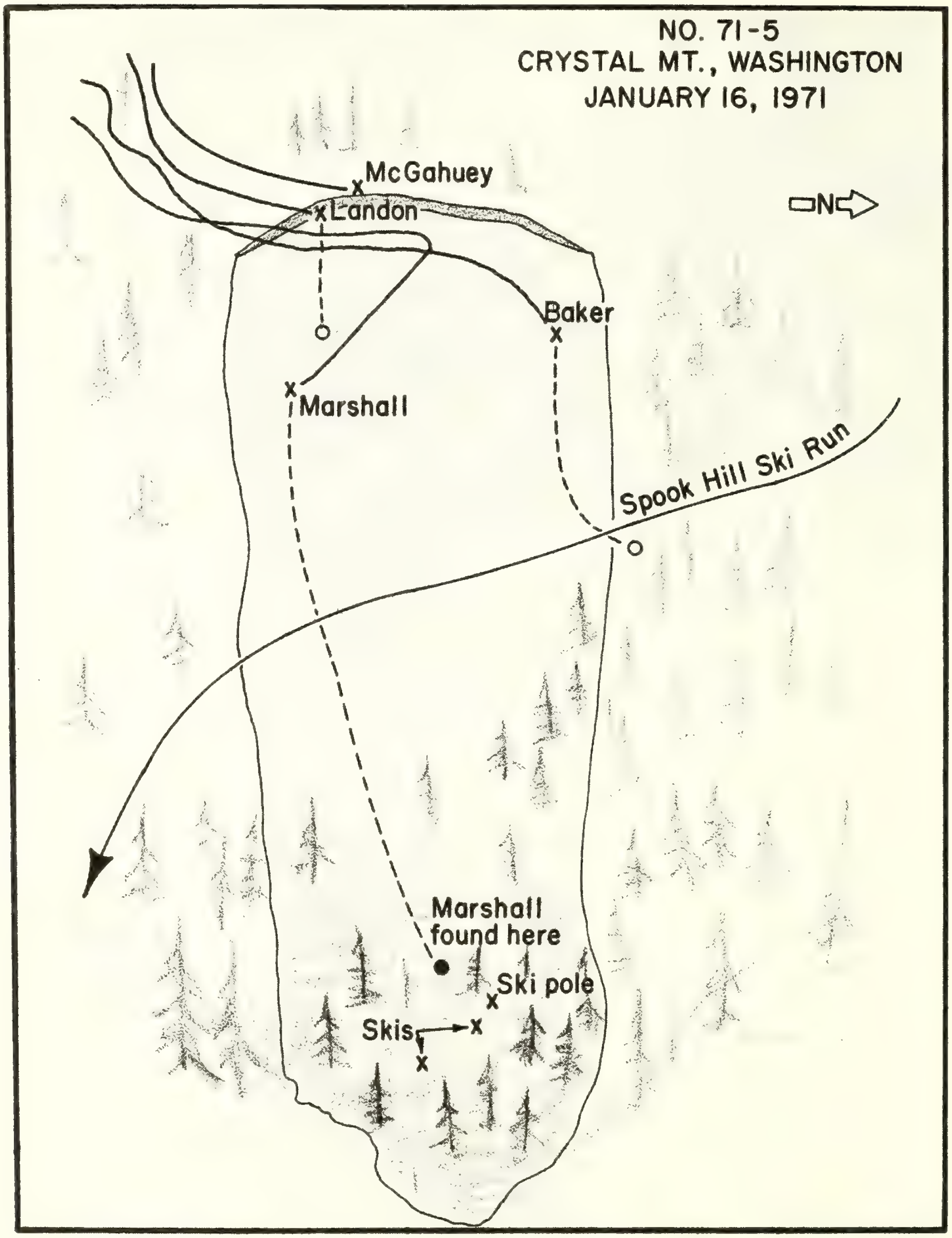
"We then met on top of the mountain to gather our explosives for the trip to Angle Ridge to control the chutes over the housing area. We arrived over the area at the appointed time and checked by radio below to the housing area to determine if all was clear. After several hand charges had released one small slide, we determined that the area was safe; it had already slid out the day before.

"Ray and I fired the Angle Ridge avalanche rifle into Brand X area while Jerry Landon, a volunteer patrolman, and Mike Marshall, a pro patrolman, observed and took pictures. We knocked down one large avalanche out of Pucker Gulch that ran a quarter of a mile down the Northway Trail. After cleaning the rifle, we skied down under the Niagara Chutes to check action. We found them all clean and safe. We then headed for the last chute which overhangs the lower Spook Hill run.

"We arrived there at 1155. We paused for a moment while we waited for Jerry. He was having trouble with a ski binding. We discussed control of the chute. We probe-tested the snow and determined that it had slid previously. There did not appear to be much snow in it. We decided to ski it out.

"Ray skied across the chute and side slipped about 25 feet down the opposite side and stopped. Mike skied out, kick turned and side slipped about 50 feet down the other side. I skied out to the top-middle and again tested the snow; it appeared to be okay. Jerry came out behind me.Suddenly the whole mountain seemed to move, at first almost in slow motion. The fracture opened up under Jerry's skis; he fell down the path about 25 feet. Ray and Mike started down with the avalanche. Mike's skis were pointed downhill, he was skiing down with the slide but appeared motionless relative to the moving snow. After 150 feet, Ray scrambled out to the side. We both watched Mike gathering speed with the avalanche; he seemed caught in a giant vise. The avalanche narrowed and went over a knoll; there was a large white cloud and Mike disappeared. I cannot tell you all the things that went through my mind during this instant. I was left high and dry. It had broken about 4 feet below me. Ray skied down the slide path calling Mike's name with me right behind him. Jerry was back on the path with a broken binding.

"As soon as Ray and I reached the last point at which Mike had been seen, we saw the avalanche had run another 200 feet onto a flat area. All was quiet and white. No Mike! Jerry was carrying the radio, so we immediately set


NO. 71-5
CRYSTAL MT., WASHINGTON
JANUARY 16, 1971
N
McGahuey
Landon
Baker
Marshall
Spook Hill Ski Run
Marshall found here
Ski pole
Skis

the rescue operation into high gear. I gave directions on how to get there, gave instructions to send all available manpower, and ordered search and rescue dogs, a doctor, a toboggan and an ambulance."

Rescue

"While waiting for the hasty search party to arrive, I studied the slide to determine flow and then looked for clues. Fifty feet up from the bottom, I found one ski pole and 5 feet below that I found one ski; another 25 feet below that I found the second ski. Ray and I along with Jerry probed the area with our ski poles. We then searched likely areas where a body could lodge. The avalanche occurred at 1205; at 1305 the hasty search crew arrived led by Gordon Burlingame with six patrolmen.

"I put them to work probing likely spots. After about 10 minutes, I took them and formed a probe line where we had found the lowest ski. After 10 minutes, Endrik Noges and eight more people arrived, and I appointed Endrik as probe-line leader and we put all the men on the line. After 10 minutes and about 50 feet of probing, Jack Hadfield cried, 'I hit something.' The shovelers started digging. The probe line continued on. The something proved to be Mike. As soon as his face was uncovered, he started hollering. What a beautiful sound! This was at 1335, exactly 1½ hours from the time the avalanche was triggered. Mike was found in a prone position, head downhill with one hand by his mouth and nose. His mouth and nose were free from snow. At this time Dr. Krengel arrived and shortly after that, more follow-up crews and the toboggan.

"The snow was carefully removed from around Mike so that the toboggan could be moved in on a level with him. He complained about pain in the pelvic region and his legs. He was immobilized as he was put into the back splint and then was moved into the toboggan. Mike was in the ambulance and away at 1430.

"In addition to being in deep shock, Mike's injuries consisted of a broken leg, both bones, just above boot top, a cracked pelvis and his hip socket was jammed from the force, possibly causing the pelvis fracture. Mike says that he is thankful and that his life could not have been entrusted to a better bunch of people."

Avalanche Data

This avalanche was classified as a SS-AS-3 and was triggered by the four members of the control team. The snow fractured directly under the skis of Jerry Landon, who then fell into the 3-foot-wide void when the slab moved out. The avalanche had characteristics of both a wet and a dry avalanche; it grooved the bed surface in places but also threw up a dust cloud after dropping off a knoll in the path. Skiing conditions in the area were described as 'mashed potatoes'."

The slope was a lightly timbered, northeast-facing path with a steepness of 35° in the starting zone. The avalanche started at the 4,900-foot elevation and dropped to 4,450 feet. The upper part of the slide path is a rock slide; it then flows over a knoll into the runout zone which is covered with numerous trees. The debris was as deep as 8 feet in this area.

Comments

The victim was fortunate to have survived this ordeal. He was buried under 4 feet of heavy snow, lying in a prone position with his head downhill. He had been able to get one hand close to his nose and mouth, keeping them free from snow or obstructions. The pole straps were off his wrists and no safety straps were worn on his skis. All ski equipment had come off and this may have helped him get his hand into position.

His body position, however, was not favorable. The prone body position and his severe injuries resulted from hitting a tree. Marshall vividly remembers being swept directly into a tree, hitting it with full force. He was then thrown forward onto his stomach and face and was helpless to improve his position.

This kind of accident is apt to happen to any avalanche worker during his career. Control skiing leads to numerous minor accidents and a few severe ones each winter. In this accident, both of the U.S. Forest Service skiers were carrying Skadis, but the two ski patrolmen were without. A rescue within minutes would have been the result if Marshall had had a Skadi. Skadis (or any of the other avalanche rescue beacons) are strongly recommended for all avalanche control personnel.

2 caught; 1 partly buried and injured

Weather Conditions

During the period of January 10 to 17, 44 inches of snow containing 4.35 inches of water had fallen at Sun Valley Ski Area. The total depth at the ski area increased from 58 to 79 inches.

Accident Summary

On January 17, Ruth Murray and 15-year-old Mike LeBarron were driving along U.S. Highway 93 near Ketchum, Idaho. Four miles south of Ketchum, they stopped their car to photograph some deer. While climbing a steep, snow-covered hillside near the highway, they triggered a small soft-slab avalanche. The time was about 1400. LeBarron escaped unharmed, but Murray was swept rapidly downhill; she was only partly buried but had suffered a badly broken leg. The Sheriff's Department in Hailey, Idaho was notifed of the accident at 1442. An ambulance quickly reached the scene and took the victim to the Sun Valley Hospital.

Avalanche Data

Numerous avalanches had recently occurred in the general area, all reacting to the recent heavy snows. The slope on which the accident occurred had avalanched naturally only a day or two earlier.

Comments

Although only scanty facts are available, this accident still has a moral: when snow conditions are unstable, one does not have to travel too far to get into trouble. These unsuspecting adventurers had traveled only a short distance from their car before becoming avalanche victims. As is true of so many accidents in this volume, public education is the key to reducing the number of accidents of this nature.

1 caught, buried, and killed

Weather Conditions

The U.S. Forest Service Ranger Station in Fairfield, Idaho reported a total snow depth of 38 inches on January 15. The following day mixed rain and snow began falling; the day's total for the 16th was 6 inches of wet snow which held 0.82 inch of water. A total of 1.23 inches of rain fell on the 17th and 18th. By January 20, the storm had ended, the skies were clear, and the snowpack had settled to 24 inches. Avalanche warnings for the Sawtooth National Forest had been broadcast on January 14, and this warning was still in effect on the 20th.

Accident Summary

On the morning of January 20, a party of snowmobilers were enjoying a day's outing along Willow Creek, 15 miles east of Fairfield. They were on private land and were driving their machines on the hillsides on both sides of the creek. At 1215, Bill France got his machine stuck in the heavy, wet snow about a third of the way up a steep pitch. John Sabala was at the creek bottom and Gary Osborne was on the opposite hillside at the time.

As France was trying to dig his machine out, the snow fractured about 200 feet above him—about 30 feet below the ridge crest. France had no chance to move and was overwhelmed by the heavy snow. Sabala was at the bottom of the slope and had time to escape the fairly slow avalanche by going up the opposite hillside.

Osborne viewed the entire accident from the opposite side of the creek. The avalanche ran to the creek bottom and stopped. France's snowmobile was pushed ahead of the slide and came to rest on top of the avalanche, but there was no trace of France. The men briefly searched the area but could find no clues; then one of them left to bring additional help.

Rescue

The Camas County Sheriff's Department and the Soldier Mountain Search and Rescue unit both responded to the call for help. But several hours had passed before the rescuers were on the scene and a probe line established. Finally at 1615, 4 hours after the accident, the body of Bill France was found by probers. He was found 50 feet downhill from where he had been struck and was buried beneath 9 feet of snow. Suffocation had obviously come within minutes of being buried.

Avalanche Data

This was a medium-size, wet-slab avalanche that was released by a snowmobile and its driver. The fracture line was 2 feet deep. The snow ran 300 feet down the slope—a vertical distance of 163 feet. The total avalanche area was approximately 3 acres and all of it slid on an old ice layer. The snow was heavy and wet from the rain that had fallen 2 days earlier.

This part of Willow Creek lies at an elevation of 5,600 feet. The avalanching slope has a northeast exposure and a steepness of 33°. The slope is completely bare of trees and the sagebrush ground cover lay well beneath the snow surface at the time of the accident. There was no previous history of avalanches on this slope.

Comments

There were no reports of this slope having avalanched for at least 40 years; yet it possessed, under the right conditions, all the characteristics of an avalanche slope. A deep snowpack covered all the vegetation, and recent snow and rain had heavily loaded the slope. The slab failed under the additional weight of a snowmobile. This snowmobile party had not heeded the recent avalanche warning, evidently thinking that they were not traveling over avalanche terrain.

The victim would have probably died even if he had been quickly found by his companions. The necessity of sending for outside help sealed his doom. Under such a depth of heavy, wet snow, life is measured in a few short minutes. During extreme avalanche conditions, anyone near the floor of a V-shaped canyon is in a highly vulnerable position. Any avalanche that releases above him will bury him hopelessly deep as the snow fills the canyon bottom.

16 caught; 13 buried; 4 injured; 4 killed. 7 cabins damaged

Weather Conditions

The Cascades were in the midst of their most severe winter in many years. Snowfall had been heavy with record snow depths accumulating in some areas. By mid-January, more than 100 inches of snow covered the mountain slopes around the Stevens Pass Ski Area. Precipitation was recorded on 20 consecutive days between January 8 and 27 at Stevens Pass with daily water amounts ranging from a trace to 2.90 inches.

A major storm that would lash the area for 6 days began on January 20. At Stevens Pass, the precipitation occurred as follows: by 0800 on the 21st, 14 inches of snow containing 1.57 inches of water had fallen; on the 22nd, 12 inches of snow, 1.33 inches water equivalent; on the 23rd, 9 inches of snow, 1.14 inches water equivalent; and by midnight on the 23rd, 14 additional inches of snow with 1.50 inches water equivalent. All during this period the winds were westerly and averaged 30 to 45 m.p.h. without letup. The anemometer stopped operating on the night of the 23rd, and no more wind readings were possible for the remainder of the storm.

Accident Summary

Yodelin is a private development of "second" homes which lies along U.S. Highway 2 just east of the summit of Stevens Pass. In 1968, construction began on several cabins at the foot of a steep, east-facing mountainside. The cabins of Barton Edgers and Milo Stoen sat side-by-side at the foot of this slope; both were two-story cabins.

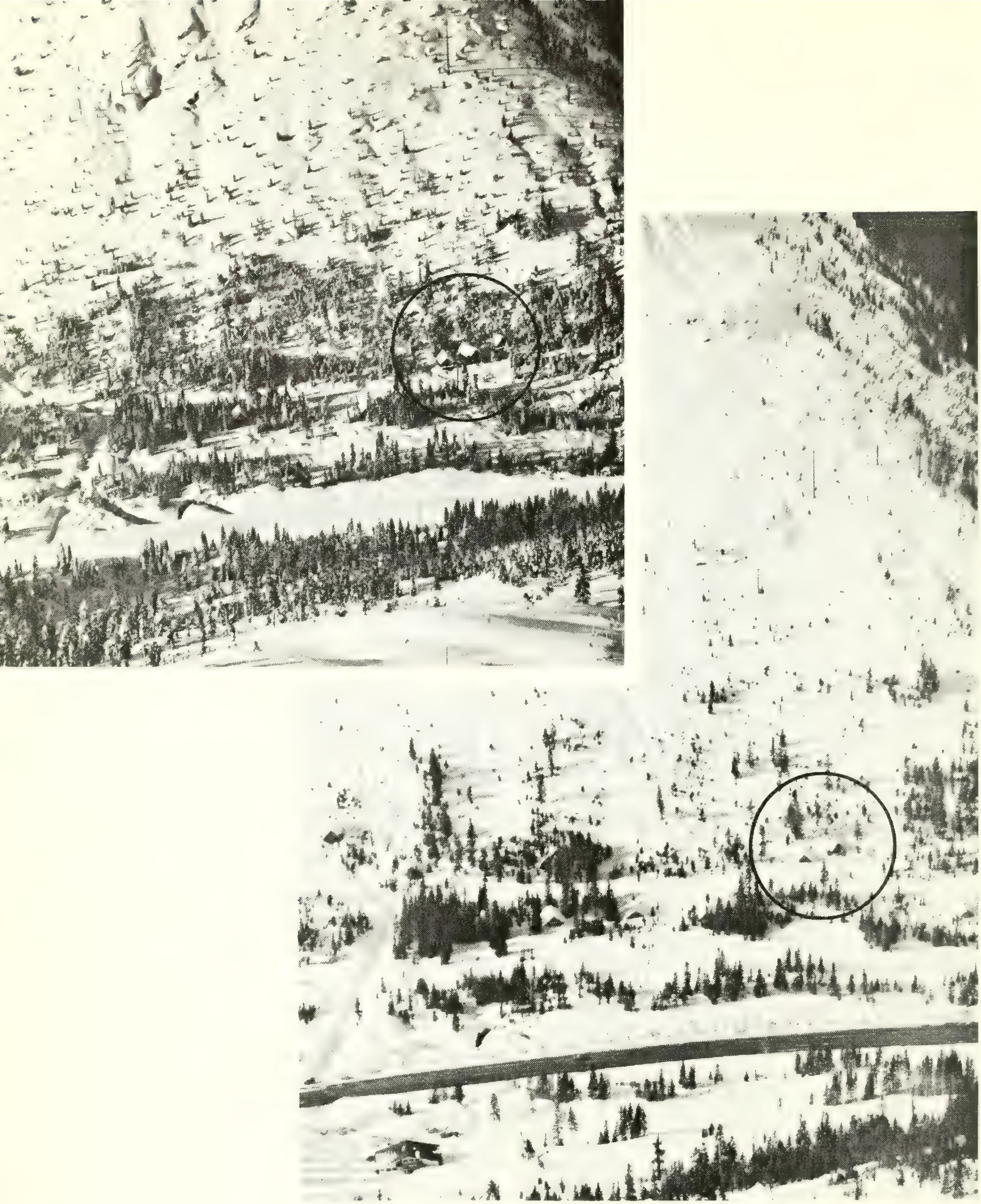
On the weekend of January 23 and 24, there were 16 occupants in these two cabins. In the Edgers cabin were Mr. and Mrs. K. Barton Edgers, 43 and 41; their children, Deborah, 19, and Cindy, 14; Mr. and Mrs. Billy G. Lewis; and their children, Kenneth, 10, Mark, 8, and Richard, 5. In the Stoen cabin were Mr. and Mrs. William Dean; their children, Linda, 15, Nancy, 14, Peggy, 12, and John, 8; and a friend, Judy Hewlett, 12.

The storm was still raging when the residents of the two cabins went to bed on Saturday night (January 23). Near midnight on Saturday, or in the early morning hours of Sunday (the 24th), an avalanche released above the cabins and struck them full force. The Edgers cabin was demolished; it was ripped from its foundation, and pieces of walls, roof, and boards were carried more than 100 feet downhill. The Stoen's cabin was engulfed with snow crushing the back wall and roof and filling the upstairs bedrooms. A third cabin —this one unoccupied—was also struck; the rear wall buckled and snow spilled into the living room. Residents of neighboring cabins were unaware of the disaster until survivors from the Stoen's cabin came calling for help.

Rescue

A resident and developer-owner of Yodelin, Wendell Carlson, was one of the first persons alerted by the survivors. Within minutes Carlson had notified the Yodelin Ski Patrol, the Stevens Pass Ski Patrol, the Chelan County Sheriff's office, the Leavenworth Volunteer Fire Department, the State Highway Department, and the U.S. Forest Service. The Yodelin patrolmen were the first rescuers on the scene. With the help of William Dean, who had escaped from the slide, they began searching the upstairs rear bedroom of the Stoen cabin in which Peggy Dean and Judy Hewlett were sleeping. The room had been completely filled with snow. After a short period of digging, both girls were found. Both were unconscious, and mouth-to-mouth resuscitation and external heart massage were immediately administered. The Hewlett girl responded and was revived within minutes. Peggy Dean did not respond in spite of being worked on for several hours. She was finally pronounced dead, a victim of suffocation. All the other occupants of the Stoen cabin survived without injury.

Meanwhile additional rescuers began searching the wreckage of the Edgers cabin for survivors or bodies of the dead. The broken sections of the house were completely buried beneath the snow, but probing soon revealed the wreckage of the upper story. Voi-



No. 71-8. Yodelin, Stevens Pass, Washington. The photograph on the left is an aerial view of part of the Yodelin development on December 20, 1968. Note the three cabins circled. The photograph on the right is an aerial view of the same area taken on January 28, 1971, four days after the accident. Note that within the circled area many trees and the rightmost cabin are missing. These were destroyed by the avalanche.

ces could be heard beneath the debris, but clearing the wreckage with shovels, chain saws, and axes was slow work.

After cutting through the roof, the rescuers came across the Lewis family who had been sleeping upstairs. Mr. and Mrs. Lewis were found alive after being buried an hour and a half, jammed in their sleeping bags under a heavy beam of the cabin. This beam had supported the roof above them, giving them a breathing space and saving their lives. Minutes later their son Mark was found alive, but 10-year-old Kenneth was removed from the wreckage, dead from suffocation. Richard Lewis was still buried somewhere in the ruins.

It was from Lewis that the rescuers learned that nine persons had been in the cabin and that all four members of the Edgers family were unaccounted for. Mr. and Mrs. Edgers had been sleeping upstairs and the Edgers girls had been sleeping on the lower floor. Digging through the wreckage soon produced the bodies of Mr. and Mrs. Edgers, both dead from suffocation. They were found only 8 feet away from where the Lewises had been rescued alive.

The rescue continued throughout the night with a portable gasoline generator from Stevens Pass providing light for the searchers. An avalanche guard had been posted to warn the rescuers in the event of another avalanche. In addition, the occupants of six or seven other cabins in the area were evacuated from their homes.

By dawn, the number of rescuers had thinned out as most of the ski patrolmen returned to their jobs and the volunteer firemen returned to Leavenworth. Less than a dozen men remained at the disaster site. It had been several hours since anyone had been pulled from the wreckage, and the rescuers felt little hope of finding anyone else alive. Already, four lifeless bodies had been taken out. Three victims—Richard Lewis and the two Edgers girls—remained buried somewhere beneath the tangle of snow, lumber, and household goods.

A bulldozer was brought in after daybreak to remove some of the debris. But it wasn't until about 1030 that one of the rescuers heard a sound in the same area that the Lewises were found. Minutes later 5-year-old Richard Lewis was pulled out from under a section of the roof. He had been buried for 10 hours and was suffering from hypothermia and shock, but was otherwise in good condition.

Finding this boy alive renewed the hope that others may have survived. The two remaining victims had been sleeping on the main floor of the cabin and as yet this had not been found. The rescuers devoted all efforts to digging down to this level.

At noon, a sound was heard as another section of cabin was uncovered; soon a small dog was dug out—frightened and half frozen, but alive. Shortly, when the front door and porch were uncovered, the position of the two Edgers girls could almost be pinpointed. But this necessitated digging about 10 feet into a 15-foot-high wall of snow. At 1300, voice contact was made with the girls. They were still alive!

It took another half hour of digging to break through to where the girls were pinned under a section of the back wall. The wall had collapsed over their bed but had also shielded them from most of the snow and allowed a small breathing space. After being buried for more than 12 hours, Debbie and Cindy Edgers were pulled, frightened but unhurt, from their prison of snow.

Now that all the victims had been found, the rescue was concluded. The area was then evacuated for fear of more avalanches. All the survivors, some of whom were injured, were taken to the hospital in Wenatchee for treatment and observation.

For the victims who escaped alive, the experience was harrowing. As the avalanche struck, Mrs. Lewis said she heard a rumbling and a crackling sound; Mr. Lewis recalled only being squeezed. They were jammed in their sleeping bag under a beam of the cabin in a cramped, yoga-like position. Lewis had one arm free and could even touch his children. He remembered it being very hot and having to search for snow to put on their faces and in their mouths.

Downstairs in the same cabin, Deborah and Cindy Edgers had been sleeping in a roll-out double bed when the slide hit. Debbie said she first realized what had happened when her sister started screaming. The wall had caved in, falling over the rigid headboard and forming a kind of tent. There were triangular openings at each end and a cool breeze came through. Debbie remembered waking up and feeling around. It was cold and the snow had enclosed them all around. She could move a little, and Cindy could move except for one of her legs which was pinned.

Shortly after the avalanche struck, Debbie heard a child cry out—probably one of the Lewis children; she also heard her dog whimpering. Both girls were in their bedclothes and were fairly comfortable at first; then it started getting damp. The snow began to settle and confined them more and more, but it was still warm in the enclosed space. Eventually they heard the sounds of searchers working above them and the vibration of tractors. They called out and pounded on the wood, but they didn't think they would be found in time. But when the rescuers finally broke through to them, both girls burst into tears when they realized that they were going to be okay.

Avalanche Data

There appear to have been two distinct avalanche cycles in the Stevens Pass area. The first cycle began on January 22 and ended on the 25th and was mainly made up of soft-slab avalanches. These were in response to the heavy snowfall, strong winds, and continual below freezing temperatures during the period of January 21 to 25. The second cycle occurred on January 26 and 27—after the Yodelin tragedy—and consisted of wet-slab and wet, loose avalanches too numerous to count. These were induced by warmer air and rain marking the end of the storm which had begun on January 20. Many of these wet avalanches ran on top of dry avalanches of the first cycle.

The Yodelin avalanche occurred during the first cycle and was a natural soft-slab avalanche (SS-N-3). Approximately 300 feet wide, it ran about 700 feet vertically and had an estimated 3-foot fracture line. This east-facing slope has a steepness of 40° in the area where the avalanche released. Trees of more than 1 foot in diameter were bent over or snapped off by this slide. About the same time as this avalanche, another slide struck and damaged the chapel at Yodelin, several hundred yards from the destroyed cabins. In all, six slides were observed on the Yodelin slope. The following day (January 25) a large slide came off Lichtenberg Mountain to the north of the development. This slide rode over a bench part way up the mountain and continued down the slope, striking three additional cabins in the Yodelin development. Two of these were totally demolished and the third was severely damaged. None were occupied; however, one had been evacuated only the day before.

Comments

No case can better exemplify the need for avalanche zoning than this one. The toll in this tragic accident was 13 persons buried, 4 injured, 4 killed, and extensive loss of property. A strong zoning ordinance would have prevented these cabins from being built. This accident was not the result of a "freak" avalanche, for the area has an established history of avalanches. In February 1910, the area was swept by avalanches that killed two men; this was during the same cycle that produced the Wellington train disaster just a few miles away on the opposite side of Stevens Pass (see *The Snowy Torrents* No. 10-1). Then in 1948 a large avalanche came down the Yodelin slope and crossed both Stevens Creek and the highway. This was a much larger slide than any of those occurring in January 1971.

Concern about the avalanche hazard in the area was first voiced in 1966 and again in 1968 when construction began in the development. Nevertheless, lots continued to be sold and homes continued to be built beneath the steep slopes.

Even before the tragic slide of January 24, the homeowners at Yodelin had been alerted to possible danger. In the spring of 1970, a small slide had come through the back door of the Edgers cabin, spilling considerable snow into the kitchen. And earlier in the winter of 1970-71, the cabin had been struck again. These experiences had caused Mr. Edgers to run a cable from the main floor to a large rock behind the cabin to keep it from being moved off its foundation. The back windows and door were also boarded up for wintertime use. These precautions are a classic underestimation of the destructive forces involved. Apparently, only one family at Yodelin heeded the warning signs and left for the winter.

So the key to preventing future accidents of this kind is twofold: avalanche zoning and public education. In the absence of strong zoning regulations, the buyer must be made aware of the avalanche threat in mountainous terrain. In the aftermath of the Yodelin disaster, lawsuits were filed by the survivors of the accident against the developers of Yodelin. One suit has been settled out of court; another is still pending.

1 caught, buried, and injured; 1 vehicle buried

Weather Conditions

The weather conditions contributing to this accident are described in No. 71-8. Heavy snow continued to fall all during the day on January 24. While the rescue was in progress at Yodelin, numerous avalanches hit the Stevens Pass Highway (U.S. 2) blocking both the east and west sides of the pass.

Accident Summary

A highway crew was sent to the Tunnel Point area on the west side of Stevens Pass to clear avalanche snow that was blocking the highway. Two gullies of the Old Faithful slide area had released and covered the road up to 30 feet deep for a length of several hundred feet. Casey Watson and Verl Lyon were both operating front-end loaders as other men worked the debris with cats.

At about 1230, another gully of the Old Faithful group released its load of snow. The avalanche rushed out of the gully and onto the highway where it missed Lyon and his machine by only a few feet. Watson, however, was not so fortunate; the avalanche hit him full force and pushed his heavy machine across the road and up against the guardrail. The rail held, preventing the driver and machine from being swept into the canyon below. Though spared the ordeal of being tumbled down the embankment, Watson was still buried completely by the avalanche.

Rescue

The other men at the scene rushed to the rescue. They dug frantically through the snow and uncovered the cab within minutes. Snow had broken the windshield and filled the cab and was so tightly packed that Watson was unable to move. He was removed from the cab suffering from a back injury. He was taken by ambulance to the hospital in Monroe for treatment.

Avalanche Data

The Old Faithful avalanche area consists of a series of gullies that run with almost every storm and collectively hit the highway scores of times each winter. The avalanches slide down a west- to northwest-facing slope having a steepness of 38° to 40°. Avalanches starting at the top of this slope drop some 1200 feet vertically before hitting the highway; the larger slides then sweep across the road to drop another 400 feet to the Tye River. More than 1 mile of the highway is affected by the Old Faithful avalanches. These avalanches reputedly got their name in 1943 when three separate gullies ran precisely at 1-hour intervals.

These slides are controlled by a 105-mm rifle, but it was a series of natural avalanches that caused this accident. These were classified as SS-N-3 and SS-N-4.

Comments

U.S. Highway 2 was closed during the 5-day period of January 24 to 28 because of avalanches resulting from the continuing storm. The highway crews faced a major cleanup effort—and continuing avalanche peril—but managed to reopen the highway on the 28th.

While the storm raged on January 24, the avalanche danger was extreme. Whenever possible under such conditions, avalanche paths should be controlled with artillery before sending a work crew into the avalanche area. Highway crews take the greatest risk of all and are deserving of all the help they can get.

1 caught, buried, and injured; 2 vehicles buried

Weather Conditions

As described in No. 71-8, 35 inches of snow had fallen from January 20 to 23 in the Stevens Pass area of the Cascades. On the morning of the 24th, 20 more inches of snow covered the ground, and by the 25th an additional 26 inches had fallen. The snowfall over these 49 hours contained a full 5 inches of water equivalent.

Accident Summary

At about 1900 on January 25 a soft-slab avalanche released in an old clearcut area (above and south of Tunnel Creek and U.S. 2) several miles west of the summit of Stevens Pass. Directly in the path of the avalanche was a tower supporting high voltage powerlines. The tower was sheared off and fell to the ground, leaving the 345,000-volt lines intact but suspended ticklishly in the air.

A crew of about 10 men was sent by the Bonneville Power Administration (B.P.A.) into the area on the night of the 25th to restore the tower or secure the high voltage cable in some manner. As the crew was working in the darkness to clear the debris, another avalanche released above them. An unoccupied D-9 cat was hit hard and buried by the slide. A D-8 cat and its driver were also in direct line of the avalanche. The machine was struck, pushed downhill, and completely buried. The slide narrowly missed the remaining crew who were quick to come to the rescue of the buried driver.

It took several minutes before the buried cat was located beneath the mass of snow and several more minutes to dig down to the cab. After a burial of about 20 minutes, the driver was pulled from the snowpacked cab; he had received only minor injuries.

Avalanche Data

This avalanche was a SS-N-4 that fell some 1000 feet vertically down the untimbered slope. This slope faces north, has a steepness of about 37° near the top, and was the site of a clearcut sometime in the past. The first avalanche, the one that destroyed the powerline tower, was the largest of the two avalanches; it fell about 1600 feet vertically and moved a large volume of snow.

Comments

This was the third avalanche accident in 2 days in the immediate Stevens Pass area (see Nos. 71-8 and 71-9). Avalanches too numerous to count resulted from the intense storm, and multiple avalanches on any given slope were common. Avalanche hazard had reached critical proportions when the B.P.A. work crew entered the avalanche zone to perform the necessary tower repairs. Explosive control should have been used on the open slope above to protect the work team. After the second avalanche struck and buried one man, the task was wisely postponed until more stable snow conditions developed.

1 bridge damaged

Weather Conditions

Snow totaling 93 inches fell at the Alpental Ski Area on Snoqualmie Pass during the period of January 21 to 25. Total water content was 9.16 inches. On the 25th, warmer weather set in and the snow turned to rain. Temperatures in the middle thirties and total rainfall of 3.10 inches on the 24th and 26th initiated a cycle of wet avalanches.

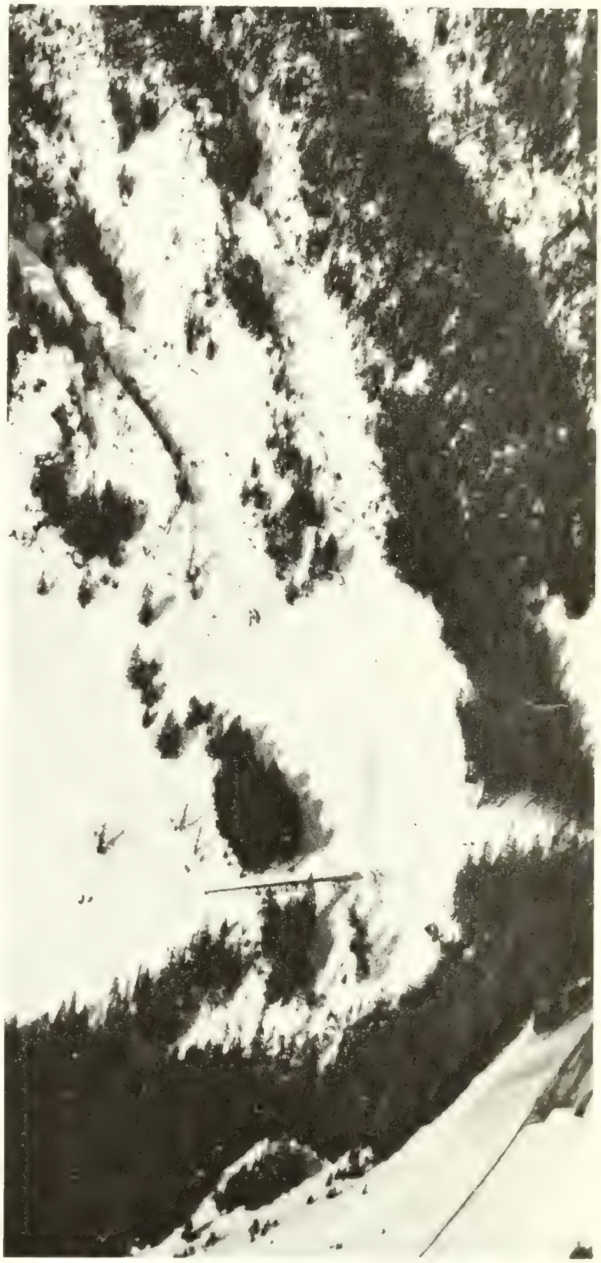
Accident Summary

A realinement of Interstate 90 over Snoqualmie Pass placed the highway along the south flank of Denny Mountain. Along this route, it was necessary to span a deep gully at a place on the mountain that overlooked Franklin Falls on the South Fork of the Snoqualmie River. A work bridge had to be constructed in this gully before the main interstate highway bridge could be built. The work bridge was fabricated from 12 x 12-inch steel "H" pilings, 18 x 43 x ½-inch welded steel-plate railroad "I" beams, and a wooden plank deck. The "I" beams weighed about 500 pounds per linear foot and ranged up to 70 feet in length.

During the night of January 26 or perhaps the early morning of the 27th, a wet-slab avalanche broke loose near the 3,800-foot level in the gully above the bridge. The avalanche traveled 1,000 feet vertically downslope before striking the bridge. A 300-foot section of the bridge was demolished by the force of the slide. The heavy steel beams and wood planking were carried another few hundred feet and deposited in the South Fork of the Snoqualmie River.

Avalanche Data

This was a WS-N-4 avalanche that resulted from heavy rain falling on a deep snowpack. The slide dropped some 1,100 feet vertically down the gully and left a grooved bed surface that is typical of wet avalanches. The avalanche packed enough force to uproot easily the heavy steel pilings that had been driven



No. 71-11. Franklin Falls, Snoqualmie Pass, Washington. The highway work bridge can be seen near the foot of Denny Mountain. In this photograph, only the left-hand portion of the bridge is standing; the right-hand portion was destroyed by the avalanche. The existing route I-90 can be seen in the lower right foreground.

into the ground. As great as the destructive force was, this avalanche path has the ability to release even higher on the slope and run even larger in the future.

Comments

This accident is a vivid example of the destructive forces of avalanches. Damage to the work bridge was estimated at $200,000 to $250,000. In addition, a delay in the construction of the highway bridge of up to 1 year may be suffered. This highway bridge is designed to span the gully completely so that avalanches can run beneath it. The possibility remains, however, that a size 5 avalanche running down this gully may reach the piers on either side and thus damage the bridge itself.

No. 71-12 Crystal Mt., Washington January 27, 1971

1 caught, partly buried, and injured

Weather Conditions

The big storm that began on January 20 (see No. 71-8 for more details) affected the Crystal Mountain Ski Area just as it did all the Cascades. From January 20 to 27, 102 inches of snow was recorded at the ski area. High winds from the west and southwest kept the avalanche hazard so high that the upper area was kept closed for several days.

Avalanche control was carried out daily, but the results of firing the 75-mm recoilless rifle were unknown because of poor visibility. On the 25th, visibility was better, and a 4-foot slab was released by rifle fire in Silver Queen Bowl. By the 27th, the fracture line had partially filled in, slab conditions had reformed, and the cornice at the top of Silver Queen had grown to a dangerous size.

Accident Summary

On January 27, five members of the Crystal Mountain pro patrol were blasting cornices that had formed from the recent snowfalls and high winds. With them was Peter Seyler, a friend and a good skier, who was along just to watch. The group headed up the ridge on the north side of Silver Queen Bowl with the intent of blowing the cornice at the top.

The time was about 1500 when the control team reached the cornice. An avalanche guard was posted along the ridge to prevent skiers from entering the bowl. Three members of the team prepared a charge for the cornice while the team leader and Seyler skied into the bowl. They were planning to cut off some sluffs on the south side of the bowl (not directly under the cornice) and then ski out of the area before the cornice blast.

The patrolman skied along just below the south ridge of the bowl. He came to a stop in a safe area and expected Seyler to be right behind him. However, Seyler had not followed the patrolman but had kick turned and skied back under the cornice. The patrolman called out to him to come to where he was. But at that moment the cornice blast occurred!

The blast dislodged a slab below the cornice; Seyler was caught in the middle and was off on a 1200-foot ride! His ski poles were lost and his safety straps were broken during the fall. He swam with the avalanche and had the sensation of being in the surf. He came up several times for air but then was pulled under. As the avalanche slowed, he found himself near the surface and was able to thrust his head up. He was at the toe of the debris when the slide stopped and was buried to the neck.

Seyler had been carried all the way to the bottom of the bowl and had to rely on help in being dug out. The posted avalanche guard and the patrol leader skied to his aid and helped him from the snow. His ski equipment was missing, and he was suffering from a painful left leg. This was later determined to be a hairline fracture of the fibula.

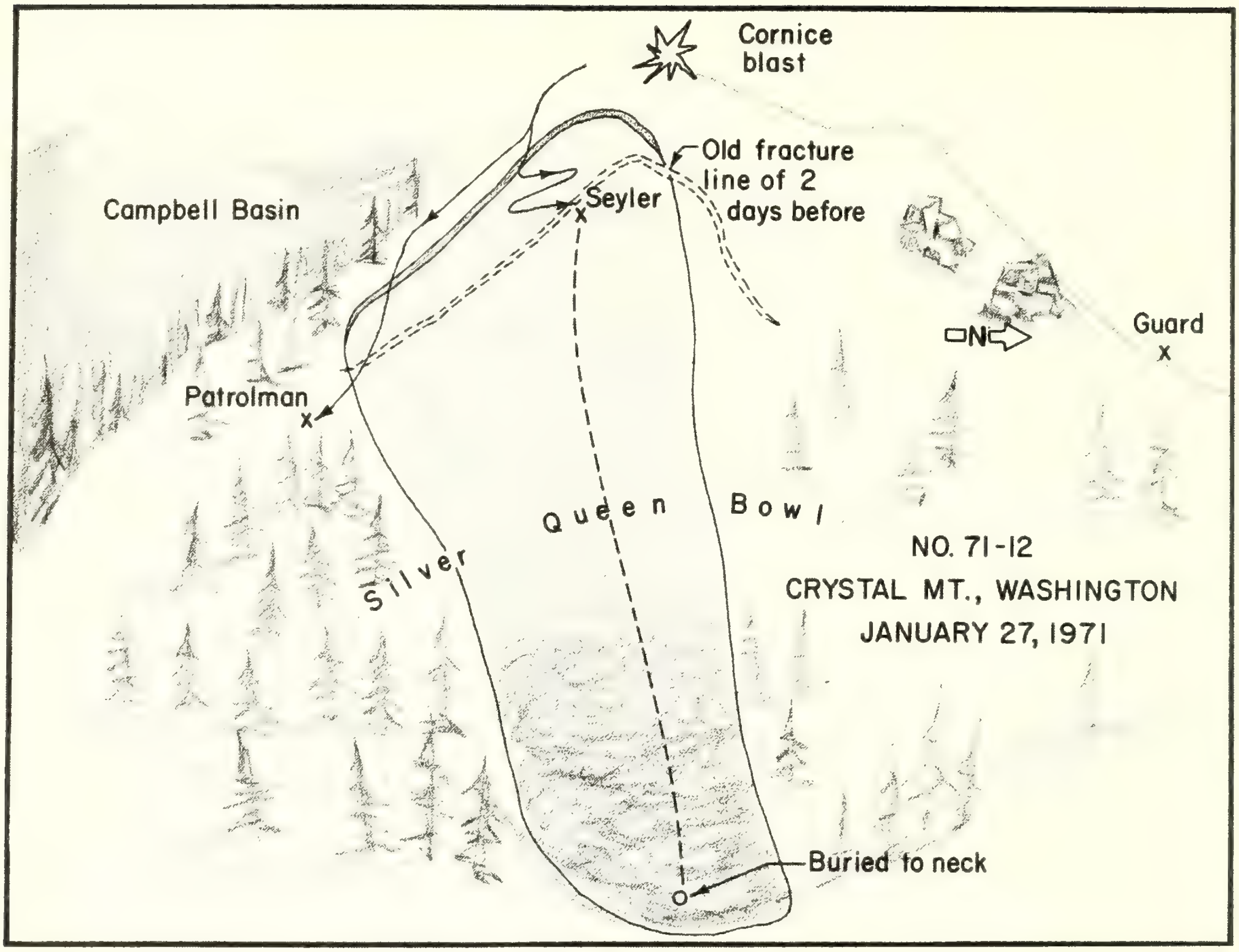
Avalanche Data

Silver Queen Bowl is an open, east-facing bowl within the ski area. It has an overall steepness of 35 ° but steepens to about 42 ° near the top. A large cornice resulting from the dominant west winds is typical along the ridge above the bowl.

This avalanche was a SS-AO-3 that resulted from the shock of the cornice blast about 100 yards away. The slide occurred on the northeast-facing portion of the bowl, fractured 3 feet deep, and dropped a vertical distance of 700 feet. A hard rain crust provided an excellent sliding surface. Debris was 10 feet deep at the foot of the bowl.

Comments

Several mistakes were made by this avalanche team, mistakes which resulted in a "close call" accident. First, it is mandatory that observers accompanying avalanche workers be kept under close supervision to prevent them skiing into dangerous areas. In this accident, this was not done. Second, there was poor communication between the blasting crew and the two skiers who entered the bowl. The cornice explosive should have never been



ignited until the blasters were certain that the area below was clear. Avalanche workers must be well drilled and disciplined on such basics of safe blasting procedures.

1 caught and partly buried

Weather Conditions

Snowfall had been light for February in the Aspen area, and the avalanche hazard was generally low. A small storm moved over the area on February 26. By morning of the 27th, 4 inches of new snow had accumulated. The storm brought cold temperatures and northwest winds averaging 12 to 16 m.p.h.; the low on the 27th was -8° and the high 8°F. Avalanche hazard remained low.

Accident Summary

On the morning of February 27, a four-member avalanche control team at Snowmass went to the area's avalauncher to fire some experimental rounds into the Hanging Valley wall. Included in the group were Tom Marshall and Dick Wall. In all, 16 more 2-pound charges were fired at the wall area. These included 10 conventional rounds, all of which exploded on contact but failed to release any avalanches. Also six experimental rounds having a different type of fuse were fired. Only two of these exploded (with no avalanches), leaving four duds in the snow.

The men then skied down to the office where Marshall and Wall talked over the dud problem. It was decided to find the duds and destroy them that day. After lunch, Marshall, Wall, and patrolman Kern Krapohl went back to the Hanging Valley area. Dick Wall stationed himself at the avalauncher platform with binoculars to direct Marshall and Krapohl by radio to the dud locations.

Meanwhile, Marshall and Krapohl arrived at the top of the wall area with four 2-pound charges for blowing the duds. Krapohl went to the first dud hole, located about 50 feet below the top of the path, and marked it with a ski pole. Marshall then moved toward the next dud which was located about 20 feet below the top of the wall. He came in under the dud hole and was about to mark it with a ski pole when the whole slope started to move.

He shouted a warning to Krapohl then looked after his own preservation. As Marshall describes it, "I saw a small aspen tree about 20 feet below me to the right. I skied for the tree and wrapped myself around it. I hung on for a couple of seconds but was pulled off the tree as it broke under the load. I went downhill over a small cliff, and the snow covered me. The snow then slid off me as it went down the hill. I continued down the hill kicking my feet and digging with my hands to keep from going farther downhill. I stopped sliding about half way down the slope. Kern was calling to me, but I couldn't talk as my chest and ribs were bruised from the tree. All my equipment—which I later found—was scattered out below me. The only thing lost was my shovel."

Marshall was carried about 150 feet vertically and fortunately did not suffer any serious injuries; Krapohl was not caught by the avalanche. Because of this accident the retrieval of duds was abandoned.

Avalanche Data

Classified as a SS-AS-3, this avalanche was about 300 feet wide and ran about 600 feet vertically. The slide paths along Hanging Valley Ridge face northeast and have a steepness of 35° to 40° near the top. Heavy timber on the west side of the ridge reduced somewhat the amount of wind-blown snow that loads these paths.

Comments

This avalanche must be included in the category of "post-control avalanches;" i.e., avalanches that run after the slopes have been controlled. In this case, two 2-pound avalauncher rounds had exploded in the area where the accident occurred. The explosion craters were located 75 to 100 feet below the line at which the slope later fractured. It was 2 to 3 hours later that the skier entered the slope, at which time it released under his skis.

One explanation of this accident is that major stability changes occurred in the 2 to 3 hours following the avalauncher rounds. Another possibility is that the exploding rounds hit a stable area of the slope, whereas the dud and Marshall were on a much weaker area. In support of this argument is the fact that snow strengths are known to vary greatly over short distances.

Whatever the cause, avalanche workers should be aware that explosives do not provide 100 percent effectiveness and should exercise caution whenever entering avalanche slopes. It is always a good policy to rope up when retrieving duds.

1 caught and buried

Weather Conditions

Jackson Hole Ski Area had received good snowfalls throughout the 1970-71 winter. On March 1, the depth of snow on the ground stood at 111 inches. A fresh storm moved into the area on the 2nd and dropped a total of 15 inches of new snow by the morning of the 5th. Although the snowfall rate was light, southwest through northwest winds exceeding 20 m.p.h. had formed moderate slab conditions. Temperatures remained cold, reaching a high of only 14°F on the 5th.

Accident Summary

On the afternoon of March 5, a party of three skiers asked permission to ski a permanently closed section in Cheyenne Bowl. The party included Jeff Roberts, Steve Rieley, and Jim Stanton. Permission was granted by the ski patrol leader without consulting the snow ranger. The party skied down Rendezvous Bowl to the Cheyenne Traverse. They then skied under a cable and signs stating "Cliff Area Closed" and started their downhill run in the powder; Stanton was on the west side, Rieley in the middle, and Roberts on the east. Roberts had made one turn under the cliff area when the slope fractured 15 feet above him. He was swept down the steep pitch and when the slide came to a halt was nowhere to be seen. His two companions searched in vain for a few minutes before Stanton went for help.

Rescue

A hasty rescue party of 10 men arrived at the scene at 1605, 15 minutes after the slide had run. The last-seen point was obtained from the two eyewitnesses, and a coarse probe line was established at the toe of the avalanche beneath this point. After 20 minutes of probing, and before the Stage II rescue party had arrived, the victim was found.

Located under 4 feet of snow, Roberts was conscious but suffering from shock. He had been buried for 36 minutes. He was taken by toboggan to the bottom of the mountain and then taken to the hospital for observation.

Avalanche Data

This avalanche was a SS-AS-2, having a 2-foot-deep fracture line that was 100 feet in length. The avalanche fell 300 feet vertically down the 37° slope. This open, south-facing slope is permanently closed and never skied, but it is hand charged because of the threat to the ski trail at its foot. The bed surface of this slide was a very definite hard, icy crust.

Comments

It is not known why permission was granted to this party to ski a permanently closed area, an area that had received no ski stabilization all winter. Had the ski patrol leader checked with the snow ranger, permission to violate the closure would have been denied and the accident avoided.

The rescue was a textbook case in speed and efficiency. The patrol was well-equipped and was on the scene in minutes. The last-seen point was marked, and coarse probing began below this point near the toe of the debris. All these procedures measured up to giving the victim the best possible chance of survival. In this case, the expertise of the rescuers was invaluable: it saved the victim's life.

1 caught and partly buried

Weather Conditions

Eleven inches of new snow was recorded at Aspen Mountain Ski Area on the morning of March 5, and two additional inches fell overnight on the 6th. Northwest winds averaging 15 to 20 m.p.h. had produced some shallow slab conditions. On the 6th at noon, the temperature was near 15°F after an overnight low of −4°F.

Accident Summary

Near noon on March 6, Mike Pokress and two companions skied outside the Aspen Mountain area boundary and onto a slope called Cristy Gully. They skied part way down the gully and stopped on Loushin's Road. Pokress was in the middle of the gully and his two companions were on the side when another skier entered the top of the path. The snow suddenly fractured beneath this skier and released a soft-slab avalanche. Pokress was directly in line with the slide and had no chance to escape. He was swept off the road and down the gully to the flats below—a ride of 300 feet.

Rescue

A separate party of three Aspen Mountain patrolmen coincidentally was standing at the top of the gully and witnessed the slide. Two of the patrolmen went down the slide path to offer immediate help while the third skied out to the patrol phone on North Star to request a rescue party.

When the two patrolmen arrived at the avalanche debris, they found Porkess completely buried except for his head and part of one arm. He was dug out unharmed. His two companions and the skier who released the slide all escaped the avalanche. Pokress skied out under his own power, and the hasty rescue party, which had arrived in the meantime, was disbanded.

Avalanche Data

Classified as a SS-AS-3, this slide had a 1½-foot fracture line and dropped a vertical distance of 600 feet. The sliding surface was a sun crust on which the new snow had fallen.

Cristy Gully is an open, east-facing slope just outside the eastern boundary of the ski area. It is a known avalanche path that is not often open to skiers, and most of the powder hounds who do ski it, ski around the steepest part and enter at a lower point on the slope. All things considered, Cristy Gully is a dangerous avalanche path that will always have its share of accidents. (In December 1972, a lone skier violated a closure to ski this path: she paid with her life.)

Comments

Skiers who enjoy skiing avalanche paths should never expose themselves to more risk than is necessary. Skiing the steep and untracked is fun, but if they survive their downhill run, they should admire their tracks from a safe vantage point, not the center of the path.

No. 71-16 **Sun Valley, Idaho** **March 13, 1971**

1 caught, partly buried, and injured

Weather Conditions

On March 11, a storm moved over the Sun Valley area and began depositing snow lightly at first but with increasing intensity as time passed. Measured snow amounts on top of Bald Mountain were 1 inch (with 0.11 inch of water) on the morning of the 11th; 5 inches (and 0.45 inch) on the 12th; and 9.5 inches (and 0.90 inch) on the 13th. Winds during the storm blew from the southwest at average speeds ranging up to 38 m.p.h. Following the storm, the winds shifted to the west.

The old snow surface onto which the new snow fell was an ice crust that had originally formed during a period of rain in mid-January. This crust had since been modified by the sun but remained as a potential avalanche sliding surface.

Accident Summary

Snow Ranger Gary Harper describes the day's activities and the ensuing accident, which occurred in an area known as 75-mm Bowl in the following narrative: "On the morning of the 13th, control work was started in the 'bowl area' of the Bald Mountain Ski Area. Supervision of the work was by myself and District Ranger John C. Combs with 14 members of the Sun Valley Ski Patrol doing the hand charging and protective skiing. We left the patrol shack at 0915 and proceeded to do the cornice control work along the top of the bowls: at each bowl we dropped off four-man hand-charge and protective-ski teams.

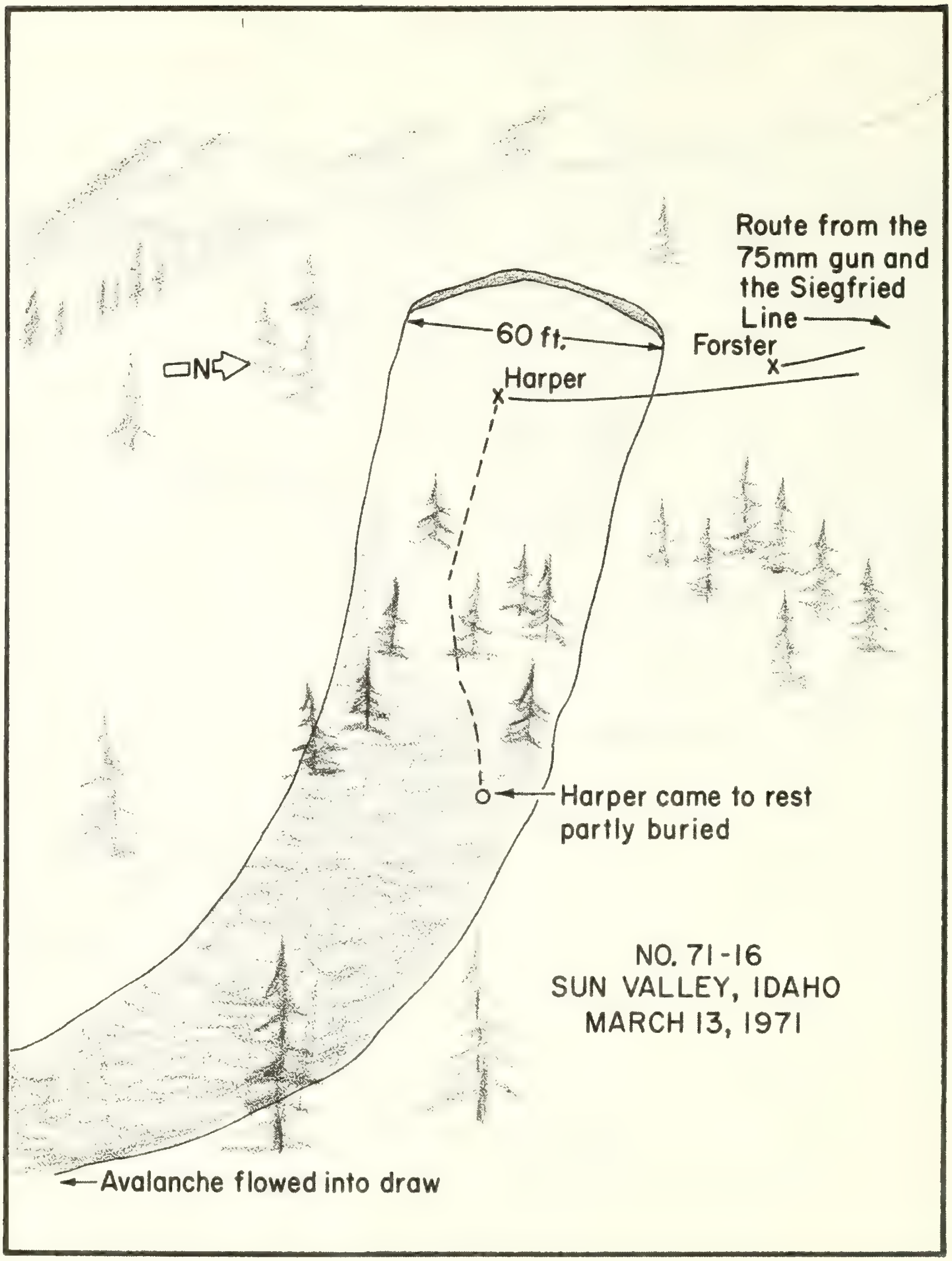
"When we reached Mayday Bowl, I decided to cut back across the area to see how the work was going in Lookout and Easter Bowl. Patrolman Dick Forster and I traversed across these areas and saw that the control teams had finished their work and were heading down. Therefore, we decided that by traversing on across we could control the small bowl located directly under the 75-mm gun.

"We came out on the ridge 100 yards above what is called the Siegfried Line. The actual area we wanted to work was about 50 yards below this road. I made two or three turns and planned to cross back to the ridge just below the road and throw hand charges from that point. I got my skis hung up in some heavy snow and was unable to make the turn back to the ridge. I called to Forster and told him to stay high, but he didn't hear me and followed my tracks on down. I told him that I thought we should be crossing 30 feet up the hill, and he said he would stay put while I went across to the ridge, some 70 feet distant.

"I had gone about 20 feet from the trees when I saw the snow fracturing around me. I looked up the hill and could see the fracture line some 20 to 30 feet above me. At this time I tried to ski forward and out of the slide but could see that I wouldn't make it, so I turned downhill to try and ski back out in the direction I had come. By this time the slab was well broken up and I was knocked off my feet. From this point on I could not tell how large the slide was. Because it was moving fairly fast, my main thought was to get stopped. I passed several trees but could not get hold of them. Finally I was able to get one ski against a large Douglas fir on the uphill side, and I think this slowed me down some; I stopped about 70 feet below the tree.

"During the slide I called to Forster to keep his eye on me. I also began to swim and found it quite easy to stay on top of the snow. My head was covered only one time for a few seconds and when I stopped I was only in snow to mid-thigh.

"At some time during the slide (probably when I came in contact with the tree), I ruptured the Achilles' tendon of my right leg. I had lost my left ski, both poles, and glasses during the slide, and the binding on the right ski had released. At this time I called up to Forster and told him that I was okay, other than my leg, and that he should go back to the ridge and ski down Easter Bowl and let the patrol know what had happened. I then used my one ski and went on down the draw to the bottom where I met Forster and the head of the patrol. We called for the helicopter and it took me on to the hospital."


Route from the 75mm gun and the Siegfried Line
60 ft.
N
Forster
Harper
Harper came to rest partly buried
Avalanche flowed into draw

NO. 71-16
SUN VALLEY, IDAHO
MARCH 13, 1971

Avalanche Data

This avalanche, classified as a SS-AS-3, had a 2-foot fracture line and dropped some 500 feet vertically down 75-mm Bowl. The avalanche consisted of only the new snow sliding on an old, icy crust. The small bowl has an east exposure and a steepness of 37° in the upper area. Douglas fir trees are scattered throughout the area.

Comments

Gary Harper had skied for 25 years and has been snow ranger at Bald Mountain since 1965; he knows the mountain as well as anyone. He offers the following observations on his accident: "All signs pointed to the fact that we might get some slide activity, and my first impulse when I found myself too low on the slope was to climb up and around. However, past experience told me that the slide should break under the rocks near the ridge. I failed to take into consideration the overall ice layer, and the very poor bonding of new snow to it. Also, there was a natural shear point or tension zone where it would be natural for a fracture to occur. We also had two hand charges which we planned to use and could have used safely before attempting to cross the slope.

"It was quite easy to stay on top of the snow (by swimming); all things I had been told to do were going through my mind, and I tried them all. The most important thing that comes to mind is that I did not pay attention to the first impulse I had, which had apparently been a correct one. This was the feeling that said: 'There is something wrong but I'm not sure just what it is!' We certainly should have used those hand charges."

1 caught, buried, and killed

Weather Conditions

On the evening of March 13, snow began falling in the Aspen area signalling the approach of another storm. By the next morning, 13 inches of snow containing 1 inch of water had fallen. West-to-northwest winds averaging 12 to 18 m.p.h. had contributed to slab formation in the area. An additional 1 inch of snow fell during the day of the 14th.

Moderate snow fell on the 15th until 6 more inches of new snow covered the ground on the morning of March 16. Northwest winds persisted on the 15th and 16th, and temperatures were mild with highs in the upper twenties.

Accident Summary

On March 16, Deep Powder Tours, Inc., which operates snow cat tours in the backcountry, had a party of eight skiers ready to hit the new snow. In addition to the skiers were co-owner Tom Cleary, ski guide Tom Simpson, and snow cat driver Glen Sharp. They were to ski the slopes off both sides of Richmond Hill, south of Aspen Mountain Ski Area.

By afternoon, the party had made five downhill runs and was headed for the slope between Independence Bowl and Black Diamond Bowl on the east side of Richmond Hill. While en route, they noticed four sets of fresh ski tracks entering the north draw of Independence Bowl. After unloading at the top of their ski slope, it was agreed that guide Simpson would ski over to the south draw of the bowl to see if these unidentified skiers had safely departed. Independence Bowl, also known as McFarlane Gulch, is recognized as a high-hazard avalanche path and is almost never skied: thus, Simpson was concerned that the four skiers might have been caught in an avalanche.

While Simpson went to check out the ski tracks, the rest of the group was to ski on down; the ski party, the snow cat, and Simpson were all to meet at the bottom. The time was about 1500 when Simpson skied off from the group.

The ski party met the snow cat a short time later, but Simpson did not appear. Thinking he had been delayed, they rode the snow cat back up and took another ski run down the slope. When Simpson had still not shown, they rode the cat up to the top of the south draw of Independence Bowl to look into the area. What they saw was shocking; almost the entire bowl had avalanched with Simpson's tracks leading into the fracture line. There was no sign of Simpson!

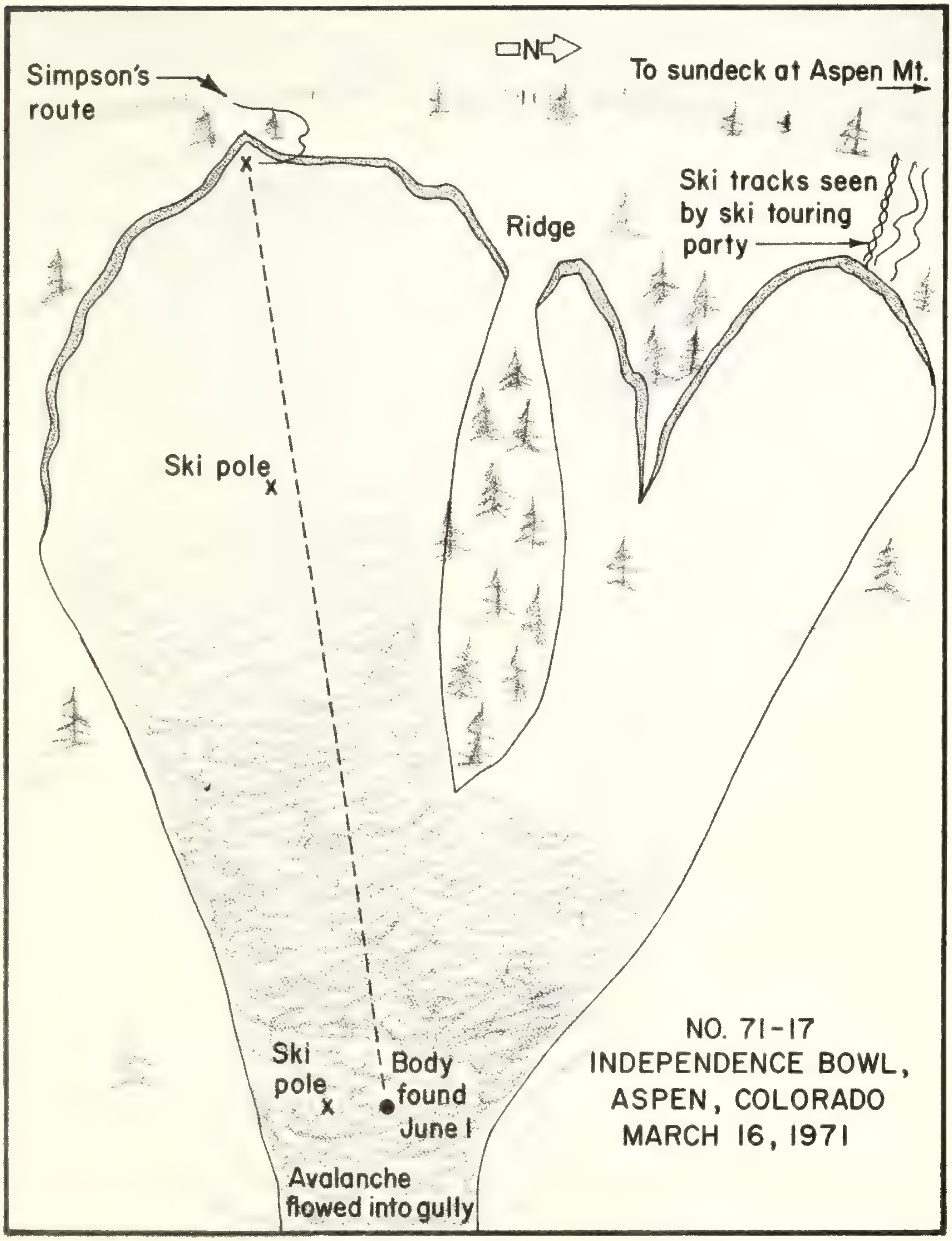
Rescue

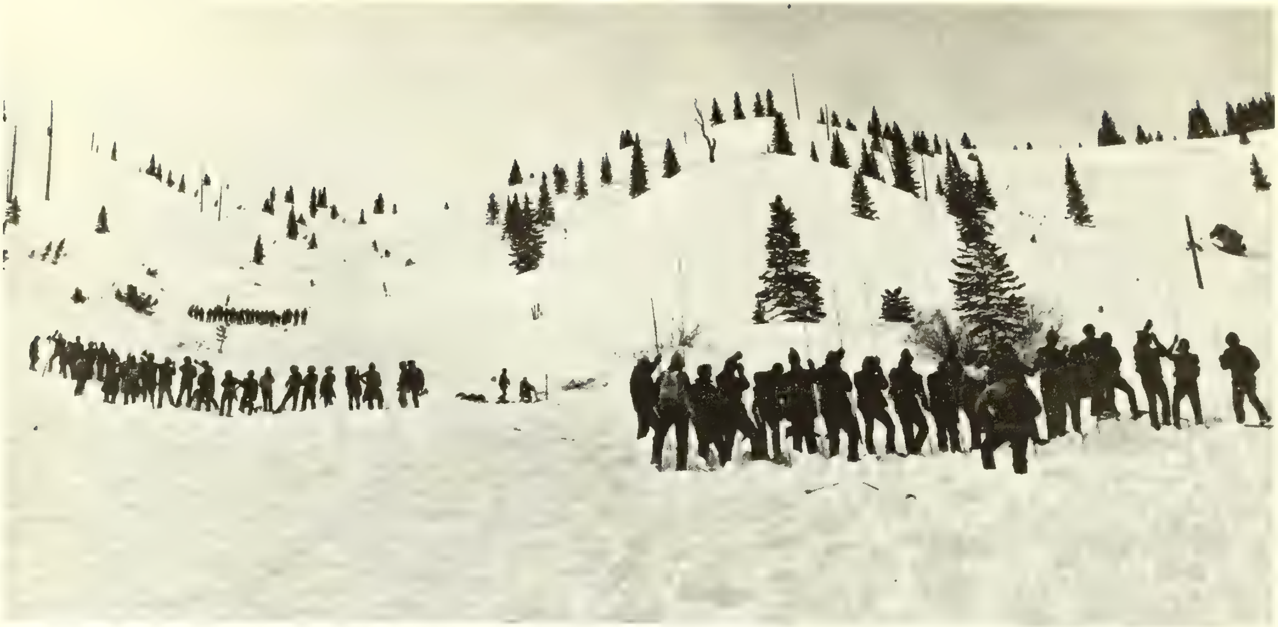
At this point, the snow cat was sent to the Sundeck at Aspen Mountain to summon help while Cleary led the rest of the ski party on a hasty search. Already 1 hour had elapsed since Simpson had left the group; and after the hasty search group failed to find any sign of him, his chance of survival was dimmed even further.

The Aspen Ski Patrol, the U.S. Forest Service, and Mountain Rescue - Aspen were all notified of the accident by Glen Sharp, the snow cat driver. Eight Aspen patrolmen were on the scene at 1635, about 1½ hours after the accident occurred. Soon, one ski pole was found a short distance below Simpson's entry point, and some time later the second pole was found another 500 yards down the path. By lining up the two poles and the entry point, the searchers had a good estimate of the victim's line of descent. The search was concentrated along this band of the massive avalanche.

By 1820, 42 persons were involved in the search; an hour later there were 70. A helicopter was in use ferrying Mountain Rescue personnel to the scene. Head lamps and food rations were distributed by the Forest Service as rescue efforts extended into the night. Two coarse probe lines had been established, but the hardness and depth (20 feet or more in places) of the debris slowed progress.

At 2000, the search leaders agreed to end the search for the night, and by 2030, about 5½ hours after the avalanche occurred, all the rescuers were out of the bowl. Eighty-five


N
Simpson's route
To sundeck at Aspen Mt.
Ridge
Ski tracks seen by ski touring party
Ski pole
Ski pole
Body found June 1
Avalanche flowed into gully
NO. 71-17
INDEPENDENCE BOWL,
ASPEN, COLORADO
MARCH 16, 1971



No. 71-17. Independence Bowl, Aspen, Colorado. Looking up the bowl. The victim was caught in the draw on the left. Portions of the fracture line can be seen across the top of the bowl.

searchers were present at that time. A meeting was held later that night to plan the following day's operations. It was recognized that there was essentially no chance of finding the victim alive: the rescue efforts were now aimed at recovering the body. Avalanche control in the bowl was planned for in the morning before the rescuers were sent into the bowl. Also, plans were made to provide food and equipment for up to 100 searchers.

At 0900 on March 17, blasting began in the area, and at 1000 snow cats began to ferry in the searchers who had assembled at the Sundeck at Aspen Mountain. A total of 124 searchers systematically coarse-probed the area with completely negative results. Badly deteriorating weather forced a withdrawal of the rescue group in mid-afternoon. On the following day, March 18, a similar rescue group effort was staged, again with negative results.

During the next 2 days, March 19 and 20, a different approach was taken. Two search-and-rescue dogs from the Sheriff's Office of Great Falls, Montana were taken to the accident site. The dogs worked well and uncovered numerous cigarette butts, sandwich bags, and other items discarded by the searchers, but they failed to find the buried victim. The effectiveness of the dogs was clearly hampered by the hundreds of rescuers who had trampled the area before the dogs had a chance to work it.

After 5 days of searching with probe lines and avalanche dogs had proved futile, the rescue effort was called off. It was agreed, though, that Mountain Rescue - Aspen would periodically check the bowl as snow conditions changed in the spring.

On June 1, eight men from Mountain Rescue - Aspen went to the bowl by snow cat. Upon entering the bowl, the body of Tom Simpson was immediately sighted in the lower center part of the bowl. He had been carried about ½ mile slope distance and had fallen some 1500 feet vertically. The body was located 100 feet to the side of where the lower ski pole had been found. Coarse probe lines had passed directly over this area, but the victim had been buried so deeply—perhaps as much as 18 feet—that the probe poles hadn't come close to striking him. (The great depth of the burial also explains the lack of success by the avalanche dogs.) The victim had sustained a severe head injury during the avalanche that may have resulted in sudden death.

The body of Tom Simpson was evacuated on the afternoon of June 1, thus ending the rescue that had begun 11 weeks earlier.

Avalanche Data

Independence Bowl is a tributary of McFarlane Creek on the east slope of Richmond Hill, lying about 1 mile southeast of the Sundeck at the summit of Aspen Mountain Ski Area. It lies about 1 mile south of Cristy Gully, the sight of two avalanche accidents (No. 71-15 and a subsequent accident in December 1972). The bowl has two distinct draws separated by a ridge in its upper half. These draws then converge toward the bottom of the bowl as it pitches into a narrow gully—McFarlane Gulch. The bowl covers an areal extent of approximately 70 acres, most of it only lightly dotted with trees. It has a steepness of about 33° in the starting zone.

Independence Bowl has a long avalanche history and has produced some large slides in the past. In the spring of 1965, for example, an immense slide released in the bowl, running about 2 miles in length and dropping some 3000 feet in elevation. This avalanche almost reached State Highway 82 at the valley floor.

The avalanche in this accident was a HS-AS-4, starting at the 11,000-foot elevation and running to 9300 feet for a vertical drop of 1700 feet. The slide ran a slope distance of almost 1 mile. It was 1600 feet wide at the top and narrowed to 150 feet at the toe where the debris reached depths of 20 feet.

This slide was triggered as the victim skied into the south draw of Independence Bowl; apparently the avalanche released slightly above him. Most probably then, the south draw slid out first and undercut the snow in the north draw. which then released. The accumulated snow from both halves of the bowl buried the victim to a hopeless depth. The fracture line averaged 4 feet deep, with the slab going to the ground in places, however, it slid mostly on a hard icy layer which had remained in the pack since January when the bowl had avalanched naturally. Twenty-nine inches of depth hoar lay at the bottom of the pack.

Comments

Tom Simpson, a highly competent skier, was considered to be very safety conscious and was well acquainted with the terrain and its hazards. On the day of the accident, it was his concern about the safety of another group of skiers that led him into the dangerous area where he tragically became the victim himself. This concern for another's safety led to several errors that on any other day he would not have committed. First, he entered a known avalanche area, taking a route that proved to be anything but safe. Second, he skied into the area alone. Third, he had taken no avalanche safety precautions such as carrying an avalanche cord or a Skadi.

An electronic avalanche rescue beacon such as a Skadi is highly recommended for all ski touring guides (and for members of their parties). It cannot be too strongly emphasized that the only chance a buried ski tourist has at life is to be found by his companions. A Skadi offers the best possible hope in backcountry avalanche burials.

3 caught; 1 partly buried and 2 buried; 2 killed

Accident Summary

The Eklutna Glacier lies approximately 25 air miles east of Anchorage, Alaska in the Chugach Mountains. On Saturday, April 10, two men and a woman set out on an extended climbing - ski-touring excursion. They were well equipped and carried both skis and crampons. Their plans were to traverse the Eklutna Glacier snowfields and to arrive after about a week at the community of Girdwood. The three were John Samuelson, Hans Van Derlaans, and Dr. Grace Hoeman, all experienced mountaineers.

The three climbers were driven by snowmachine to the foot of the glacier where they began their trek. Using crampons, they ascended a steep, southwest-facing slope to a cabin located at the 5000-foot level on a rock outcrop above the glacier, and there they spent the night. The weather deteriorated badly overnight so that on Sunday, April 11, they were forced to spend the day in the cabin. The weather did not improve the following day as snow continued to fall, accompanied by strong winds. Because of the weather, the group decided to cancel the rest of their tour and return to Anchorage.

At about 1330 on the 12th, the three climbers began descending the steep snowslope between the cabin and the glacier. This was the same slope they had climbed two days earlier; at that time the snow surface had been hard, following several clear, sunny days and cold nights. Two days later, however, 2 feet of new snow covered the slope, prompting the three climbers to stop before entering and discuss the safest route. In spite of poor visibility, they had seen several fresh avalanches on adjacent slopes and were suspicious about the one they had to cross. It was agreed to cross high, one at a time, and reach the relative safety of a ridge on the far side.

As Van Derlaans and Dr. Hoeman waited, Samuelson entered the slope alone and on foot, breaking trail on a high traverse. All three were wearing crampons and had their skis strapped to their packs. After several minutes Dr. Hoeman inexplicably entered the slope much lower on a steeper traverse. Van Derlaans followed.

Samuelson noticed his companions lower on the slope and came to a stop. Just as he was about to shout them back off the slope, the snow fractured all about him. He was carried helplessly downhill on a fast ride but fortunately came to rest buried only to the hips. Hoeman and Van Derlaans were totally overwhelmed by the avalanche. Both were carried out onto the glacier and were buried under tons of snow!

Samuelson managed to dig himself out and immediately began searching for his companions. He probed the debris for 2 hours with his ski pole but found nothing. With little hope of success, Samuelson began his descent, arriving at the south end of Eklutna Lake at 2030 where, because of exhaustion, he set up camp. The following morning, April 13, he reached the highway and hitched a ride to Mirror Lake where he contacted the Alaska State Troopers.

Rescue

The State Troopers immediately called the military rescue group at Elmendorf AFB in Anchorage. At 1310, Samuelson and a state trooper were picked up by a rescue helicopter and flown to the toe of the Eklutna Glacier. However, poor visibility prevented the rescuers from viewing the avalanche area. They then returned to Ft. Richardson, Anchorage, and met with the Army Mountain Rescue Team. At 1500, six members of the Army Mountain Rescue Team plus four members of the civilian Alaska Rescue Group were airlifted to the south end of Eklutna Lake where a base camp was established.

On the morning of April 14, the 10 rescuers were flown to within a short distance of the accident site. Upon reaching the avalanche area, they discovered that the recent snows had obscured all traces of the avalanche. A probe line was established, but a lengthy search revealed no sign of the buried victims. Rather than return to base camp, the rescuers dug snow caves and stayed overnight at the accident site.

Probing the following day again revealed no clues. Because of poor weather and the danger of more avalanches, the rescuers left the area at noon and were airlifted back to Anchorage. In a meeting at Ft. Richardson, it was decided that the Army would provide transportation and communications for a team of 20 volunteers from the Alaska Rescue Group to continue the search.

On April 16, the rescuers were airlifted to the accident site and a camp was established. The avalanche area was methodically probed for 2 days with negative results. Finally, on the 18th, the search was cancelled, and all rescuers were flown out of the area.

The search came to a final conclusion in early summer when the melting snow revealed the bodies of the two avalanche victims. Dr. Hoeman was found face down, head downhill, in a stretched out position with ice axe in hand. Her pack was a short distance away. Van Derlaans was found in a vertical position, head down and feet up. His heavy pack with skis still on his back; this evidently was the reason for his being found in such a helpless position.

The discovery of the bodies also revealed to the rescuers that their earlier searching and probing had been badly misdirected. Because new snow had concealed the avalanche debris, the rescuers had mistakenly probed only the very edge of the avalanche; this explained their unsuccessful recovery attempts.

Comments

The three mountaineers involved in this accident were highly experienced, a fact that makes the actions of two of them all the more puzzling. Dr. Hoeman and Van Derlaans voided the safety plans agreed upon by moving onto the slope beneath Samuelson. Instead of crossing high and one at a time, all three climbers were suddenly on the slope at the same time. This mistake proved to be fatal for Dr. Hoeman and Van Derlaans.

As a final footnote to this tragedy, it is interesting to observe that Dr. Hoeman was no stranger at all to avalanches. Indeed, her husband had died an avalanche victim himself only a few years before.

2 caught and buried; 1 killed

Weather Conditions

The Colorado Rockies were hit with two September snowstorms that left an early snow cover in the higher elevations. On the afternoon of October 15, a sizable storm moved over the San Juan Mountains. Snowfalls of 2 feet or more over the following 2 days covered the mountain peaks; Silverton received 1.17 inches of precipitation. Isolated pockets and gullies on the mountainsides accumulated snow depths of 3 to 6 feet.

Accident Summary

The Colorado elk season had begun, and hunters were swarming over the mountains on the weekend of October 16 and 17. Two hunters from Amarillo, Texas—Marion S. Martin, 48, and James Logsdon, 32—were hunting on the slopes of Pole Creek Mountain in the San Juans on October 17. It was shortly after 1600 when the two men attempted to cross a snow-filled gully on the northwest flank of Pole Creek Mt. Both men entered the gully with Martin in the lead and Logsdon behind and about 10 feet lower. Logsdon looked up in time to see the snow break above them and shouted a quick warning to his friend: "Look out, M. S., run! Here comes the snow!" Martin turned, took two steps, and was bowled over by the avalanche. He was tumbled head over heels downhill and carried out of sight.

Logsdon was also hit hard by the snow and swept downhill. But after a short ride, his rifle caught in a bush and held fast. The snow swept over him, burying him completely but shallowly. He was able to dig himself out after several minutes and began searching for Martin. He searched the snow for 45 minutes but found no sign of his companion. He also fired his rifle into the air to summon the aid of any other nearby hunters, but his call went unanswered. Logsdon finally left the area and returned to his base camp near the confluence of Pole Creek and Bear Creek at 1915 where the accident was reported to fellow hunters.

Rescue

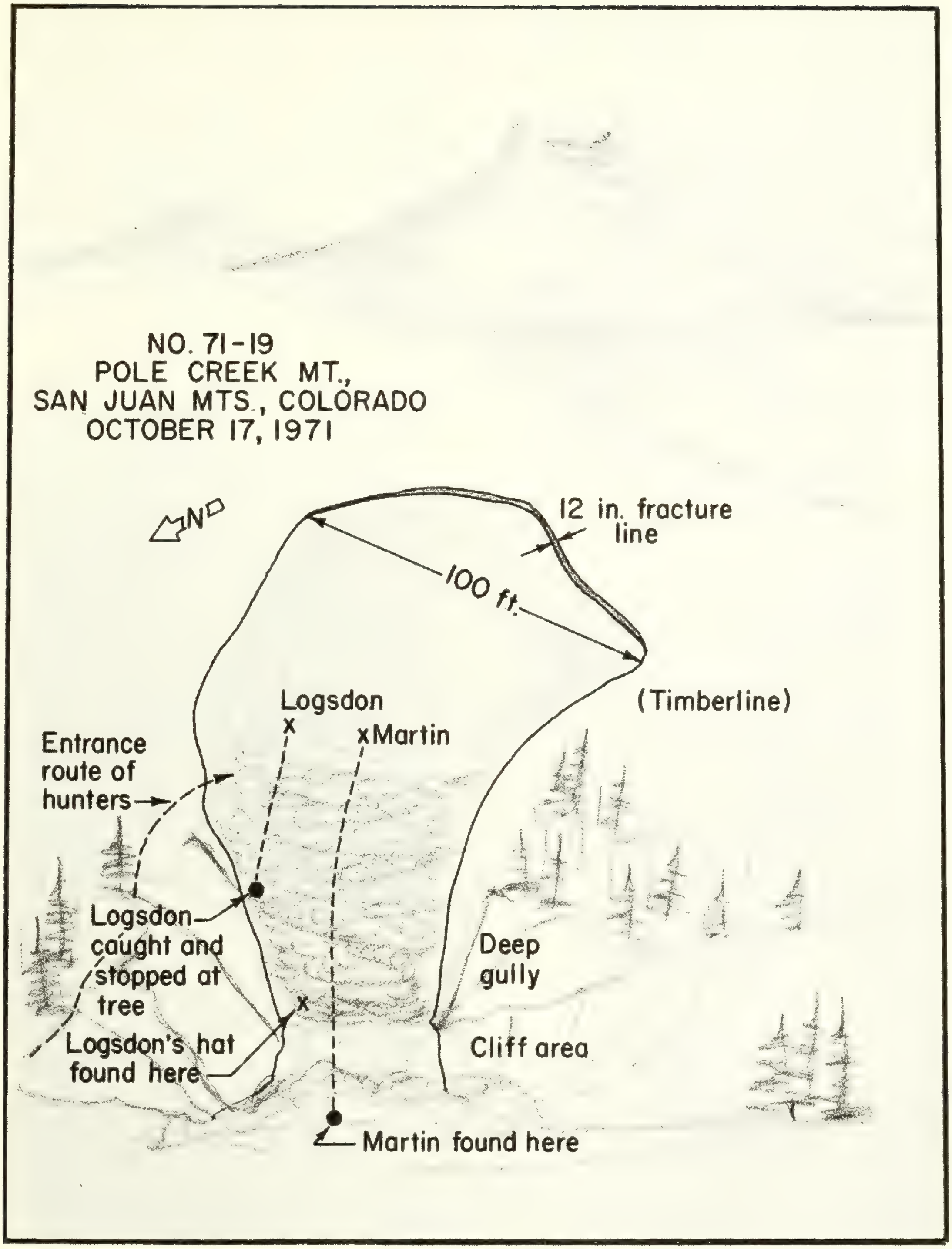
While one man drove out to summon aid from outside, a group of six hunters returned to the avalanche site. In the darkness their search uncovered no signs of the missing man.

Because of the extreme remoteness of the area, an organized rescue unit traveling in 4-wheel drive vehicles did not arrive until the afternoon of October 18, the day after the accident. The hunting camp was located 12 air miles east of Silverton and 30 air miles west of Creede and except for the possible use of a helicopter, all travel to and from the camp was over 4-wheel drive roads. At this time of year, however, almost 2 feet of new snow covered the roads with drifts up to 5 feet deep, making overland travel an adventure in itself.

The rescuers included: Don Alford of the University of Colorado Avalanche Research Project in Silverton; San Juan County Sheriff Virgil Mason and a crew of four from Silverton; Glen Hinshaw of Creede; and four members of the Adams State College Rescue Unit from Alamosa led by Greg Simmons. The ASC group was the first to arrive at the avalanche site, reaching their destination at 0930 on the 19th after a 2-mile, 4-hour uphill trek from base camp. With them was the shaken and exhausted survivor, James Logsdon. Four hours of scuffing and probing with ski poles revealed nothing.

At 1300, the remainder of the rescuers arrived equipped with 12-foot probe poles and a metal detector. A 10-man coarse-probe line was set up and covered the entire debris area in the upper half of the track. Only a hat belonging to Logsdon was found. At 1600, the search was called off because of approaching darkness and because of the threat of more avalanches in the gully. All rescuers left the site for the long walk back to base camp. Because there was almost no hope now of a live rescue, the search was temporarily halted until the slopes could be stabilized with explosives and a larger rescue unit could be airlifted in. The debris in the lower half of the track had yet to be thoroughly searched.

On October 23, 6 days after the avalanche,


NO. 71-19
POLE CREEK MT.,
SAN JUAN MTS., COLORADO
OCTOBER 17, 1971
N
12 in. fracture line
100 ft.
(Timberline)
Logsdon
x Martin
Entrance route of hunters
Logsdon caught and stopped at tree
Logsdon's hat found here
Deep gully
Cliff area
Martin found here

Alford, Sheriff Mason, and three other rescuers were helicoptered back to the avalanche site. Their job was to hand-charge any slopes that would endanger rescuers working below. A 16-man probe team would be flown in from Silverton when the explosive work was completed.

Several charges were thrown but no slides released. While awaiting the arrival of the probe team, Alford and another man walked to the base of a 20-foot cliff over which the avalanche had run. The area below the cliff had not been searched during the initial rescue effort. While scuffing this area, Alford uncovered the missing man's foot from under 6 inches of snow. Marion Martin's body was uncovered, head downhill and under 18 to 24 inches of snow. He had died instantly from a broken neck suffered in either the downhill tumble or the fall over the cliff. His right leg had also been broken in the fall. The search and rescue came to an end with the airlifting of Martin's body back to Silverton.

Avalanche Data

This avalanche was classified as SS-AO-2, being released by the two hunters walking across the starting zone. The fracture line averaged 12 inches in depth and was about 100 feet in length. The avalanche ran approximately 300 feet slope distance down the gully, digging to the ground in places. The avalanche released at approximately the 11,700-foot level on the northwest flank of Pole Creek Mt., slightly above timber line. The starting zone was the north-facing side of a deeply incised gully and was quite steep—about 50°. The avalanche was channeled to a width of no more than 50 feet in the narrow gully.

A hasty snowpit dug in the starting zone revealed 22 inches of new snow lying atop 4 inches of depth hoar. This avalanche is a classic example of an early season soft slab failing in a shallow snowpack. The depth hoar began developing in the very shallow snow cover that remained on the high-elevation, north-facing slopes after the September snowstorms. The snow and strong winds of the October storm formed a highly unstable soft slab needing only a slight trigger for release. During the period of October 19 to 23, a cycle of small natural soft-slab avalanches occurred in the San Juans as a result of this instability.

Comments

This accident focuses clearly on the dangers of a shallow snowpack - depth-hoar combination. The point is clear: *shallow pockets of snow at high elevations, and especially on north-facing slopes, are to be avoided in early winter.* The snow cover from the first storm or storms of the winter, if followed by clear, cold weather, is the breeding ground of depth hoar. It is inevitable, then, that widespread instability results when the next large snowstorm dumps its heavy load directly on top of this weak substratum. Avalanche hazard is at a maximum under these conditions.

In reviewing the rescue effort, it bears pointing out that the rescuers should have spent more of their initial effort in scuffing the *entire* debris area rather than concentrating on the upper half. Had the lower track—the area below the cliff—been scuffed, the victim's body may well have been found on the first day of the rescue.

2 caught; 1 partly buried and 1 buried

Weather Conditions

Snow began falling at Vail on November 26 as a small storm moved through the Rockies. By the morning of the 28th, a total of 14 inches of snow had accumulated. Moderate winds on the 27th had produced spotty slab conditions within the ski area.

Accident Summary

At 1115 on November 28, a group of five skiers entered Northwoods run and hugged the west edge of the run to ski the unpacked snow. The group stopped briefly on a small knoll, and then Peter King skied down the face of the knoll, fell, and lost a ski. Jackie Flater skied down to help Peter, and as she did so, the snow fractured above them. Both were carried down the short face of the knoll about 30 feet. Peter came to rest with only his head out of the snow; all that was seen of Jackie was a single ski tip. The two being side by side, Peter reached out and swept away the snow covering Jackie's face; although covered by snow, neither of them had been injured. The other three skiers helped both victims out of the snow. Peter had lost a ski; a Vail ski patrolman retrieved it later in the day.

Avalanche Data

This slide was classified as a SS-AS-1, fracturing 2 feet deep but running only 45 feet vertically. Even so, enough snow moved down this short north-facing slope to almost completely bury two skiers.

Comments

This accident is an example of the hazard to skiers from even very small avalanches. Although carried only 30 feet, Ms. Flater was completely and helplessly buried. Without the help of friends, she may not have survived this avalanche. Contrast this accident with No. 67-10 in which a patrolman skiing alone on sweep did not survive a small avalanche.

3 caught

Accident Summary

Monday, December 13, was "opening day" for the upper half of the mountain at Jackson Hole. Because all skiers riding the tram to the top must ski Rendezvous Bowl, it was mandatory that avalanche conditions be thoroughly checked out before opening the bowl. Thus, 4 days earlier on December 9, the bowl was heavily shot but with no avalanche release. On the morning of the 13th, the bowl again was heavily shot. A total of 60 pounds of HDP was used, mostly in 4-pound buried charges. Once again, no avalanches were released. At noon on the 13th, Rendezvous Bowl was opened to skiers.

The sky had been overcast all morning, but at about 1300 the clouds dissipated and the sun shone brightly on Rendezvous Bowl for the first time in many days. Two tram loads of skiers (about 100 skiers) had already skied the bowl by 1325, and the third tram load was in the bowl at this time. At 1330, after the majority of the third tram had already skied the bowl and were out of the area, the entire north half of Rendezvous Bowl fractured to a depth of 2 to 3 feet and avalanched. A number of skiers were still in the bowl and watched as the avalanche ran to the bottom of the bowl and stopped in scattered timber.

The ski patrol was immediately notified of the avalanche, and several patrolmen were at the scene within minutes. Nine eyewitnesses were quickly questioned; their statements ranged from no one caught to as many as three skiers caught. Search and probing began immediately and continued throughout the day. At the same time a check of skiers was begun to see if anyone was reported missing. By 1730, the probe had revealed nothing, and all persons who had been reported missing at various times during the afternoon were found and accounted for. The rescue was terminated at this time with strong evidence that no one had been buried. This eventually proved to be true.

Avalanche Data

This avalanche was a HS-N-4 that incredibly released when a minimum number of skiers were in the vicinity. The fracture line was 2 to 3 feet deep and was about 400 feet in length, extending from the center of Rendezvous Bowl to within 50 feet of the tree line on the north side of the bowl. Three shot holes were cut in half by the fracture line. The avalanche fell some 600 feet vertically. The runout zone was covered by debris 2 to 12 feet deep with an average depth of 3 to 4 feet. Rendezvous Bowl faces east and has an elevation of 10,300 feet at the avalanche release zone.

The avalanche ran on an old, icy sun-crust layer approximately 18 inches above the ground. Beneath this crust was a layer of depth hoar just above the ground. The avalanche broke through the crust in places, digging to the ground and exposing many rocks and boulders.

Comments

This near-accident falls into the category of post-control avalanche releases. If anything, the explosive control in Rendezvous Bowl prior to the avalanche was an example of overkill. Sixty pounds of explosives were spaced around the top of the bowl on the day of the avalanche, and a similar amount was used 4 days earlier. It is difficult to imagine how the avalanche failed to respond to such a wallop. So the difficult question arises: What really caused this avalanche? Unfortunately, we cannot definitely answer this question; we can, however, discuss three interesting and controversial possibilities that may have contributed to failure.

It is clear that the stability of the slope decreased after it was shot in the morning. So we must first ask, did the explosives contribute to the instability by either weakening the internal strength of the slab or jarring it loose from its ground anchor? There is no evidence to suggest that this happened, yet the possibility cannot be categorically dismissed.

Secondly, we need to ask: Was this a case of "temperature release"? That is, did solar radiation decrease stability to the point of failure? The sun had been shining on the slope for about one-half hour preceding release. Whether the sudden application of solar radiation to a cold snowpack or the removal of sunshine can cause avalanche release is currently a matter of debate, and needs further study (see No. 67-10 also.)

A third possibility is that the collective effect of more than 100 skiers eventually decreased the stability of the slab to the point of failure. This was the first day of skiing for the season in the bowl, and a large number of persons skiing over a completely uncompacted area is likely to either increase stress or cause a redistribution of stress within the slab; either, or both, could have caused failure.

The key word in the preceding statement is "uncompacted". This case exemplifies a classic hard-slab condition, a stiff layer of snow lying atop a hard crust and a layer of depth hoar. Without compaction, the depth hoar provides an intrinsic weakness to the snowpack, a weakness that is not corrected by the use of explosives. The only solution is artificial compaction to destroy the depth hoar and retard its reformation. Bootpacking and continuous skiing are the best methods of compaction and offer a distinct measure of safety against these mostly unexplained post-control releases.

1 caught and buried

Weather Conditions

Snow began falling over the Wasatch Range on December 23 and by the morning of December 27, 33 inches of snow had fallen on the steep slopes of Snowbird. Avalanche control had been carried out routinely during the storm without much activity.

Monday, December 27, was clear with light winds and temperatures in the midtwenties. Avalanche control on this day brought lots of sluffing and a few small avalanches. An unnamed chute in Peruvian Gulch (later named Nye's Chute) was hit in mid-track with a 2-pound charge at about 0830; no avalanche resulted. After all control teams had run their routes, the mountain was opened to the public. No closures were in effect as the result of the control work indicated that the overall avalanche hazard was low.

Accident Summary

Bret Nye, 19, had been skiing in the Snowbird area all morning and shortly before noon left the tram and skied along the ridge toward Baldy. He and three companions entered the steep chute now named Nye's Chute at the top of Peruvian Gulch. The time was 1200. A loud crunching noise was heard as the snow fractured 100 feet upslope of Nye's track. This was a deep avalanche that quickly overwhelmed the skier. His progress in the avalanche was observed for about the first 100 feet of his descent by his companions, but then he disappeared in the churning mass of snow. When the avalanche stopped, there was no sign of Nye. The chute had fractured about 200 feet upslope of the shot left by the morning's control work.

Rescue

The Snowbird ski patrol received word of the slide at 1215. At 1225, a hasty-search group of three patrolmen arrived at the avalanche site and began organizing approximately 20 skiers who had stopped to help. Five minutes later the main rescue party arrived and several coarse probe lines were established. Approximately 50 rescuers were at the scene at this time.

At 1330, after being buried for 75 minutes, Bret Nye was located by a probe line. He was found about 50 feet above the toe of the avalanche and under 2½ feet of snow. He was lying on his right side with his head downhill. A small airspace was found around his head, and he was taking shallow, gasping breaths. He was obviously cyanotic (blue-colored from lack of oxygen) but showed a good strong pulse. Mouth-to-mouth resuscitation was applied, followed by oxygen. Within 3 minutes, the victim had regained full consciousness. Further examination and questioning revealed no injuries. Nye was taken to a hospital in Salt Lake City for a complete examination and the rescue was terminated at this point.

Avalanche Data

This avalanche was classified as a SS-AS-3; it fractured up to 4 feet deep and dropped about 350 feet of vertical distance. Nye's Chute is a steep, north-facing slope dropping off the ridge between Hidden Peak and Baldy. This chute had been only lightly skied this particular winter, and considerable depth hoar lay at the bottom of the snowpack. Earlier that day, the chute had been shot, but this failed to release the avalanche.

Comments

This accident is another example of post-control release. The 2-pound hand charge was probably thrown a little too low for maximum effectiveness as the avalanche broke nearly 200 feet upslope of the shot point. As with so many post-control avalanches, this one occurred on a lightly skied slope having a weak substratum (i.e., depth hoar).

The victim is very fortunate to have survived a burial of 75 minutes beneath 2½ feet of snow. From his hospital bed, Nye related that he had at first tried to outski the avalanche but was overwhelmed and knocked off his skis. He remembered being "real scared" when the snow from above began pouring over him, but still had the presence of mind to pull both arms up in front of his face. This action formed an airspace which, without a doubt, saved his life. The pressure on his chest was great enough to make breathing very difficult.

Nye also related that he could easily hear the rescuers working over him, but his own shouts for help went unheard. Another example of this oneway propagation of sound through snow is given on No. 69-7.

2 caught and buried; 1 injured

Weather Conditions

The storm that began on December 23 (see No. 71-22) continued intermittently through the 31st, dropping moderate amounts of snow daily. The 24-hour new snow depths measured each morning were 6 inches on the 29th, 9 inches on the 30th, and 7 inches on the 31st. Mostly southwest winds had prevailed during this period. The morning of the 31st was mostly clear, and temperatures warmed from an overnight low of -1°F to near 20°F at 1100.

Avalanche control was carried out as usual at Snowbird on the 31st except for the Little Cloud chute in which an 8-pound hand charge was thrown. Cracking and settling resulted from this large charge, but no avalanche released. All runs in the ski area were opened to the public this day.

Accident Summary

The time was about 1150 when a group of eight skiers reached the top of Little Cloud and prepared to ski down the run. Several other skiers were in the area, and there were several sets of tracks down the run. Three of the group entered Little Cloud on a high traverse and were followed by two more members of the party, Mrs. Brown Dunaway and Mrs. Leonard Martin. When Mrs. Dunaway and Mrs. Martin were in the middle of the slope, the snow fractured a few feet above the two women, catching both of them. The three skiers ahead of them had already skied to safety beyond the reach of the avalanche.

Both women were swept downhill on a fast ride through widely scattered timber. Mrs. Martin covered her face with her hands to help her breathe and also tried to swim with the avalanche. She was doing all right until she hit the trees. After a ride of about 500 feet, both women came to rest near the surface of the snow. Both were able to brush away the snow from their faces and call out to other skiers who had witnessed the avalanche. Mrs. Dunaway appeared to be uninjured, but Mrs. Martin had suffered serious injuries, later diagnosed as a broken arm and several fractured ribs.

Rescue

The Snowbird ski patrol received word of the avalanche at 1200; 15 minutes later, five patrolmen and a doctor were at the scene. Both women were dug out of the snow and later evacuated by helicopter. Several of the eyewitnesses were questioned about what they saw and specifically about whether they saw anyone else caught in the avalanche. They all stated that they saw only the two women caught. However, this was a large avalanche and quite a few skiers were in the vicinity; therefore, the patrol made the quick decision that a full probing of the debris should be undertaken as a safety measure in spite of the eyewitnesses' statements. (Contrast this decision with that made in No. 70-2.)

Within an hour, eight probe lines consisting of about 100 people were coarse-probing the debris. The probe lines were made up of Snowbird ski patrolmen and ski instructors and many volunteers from skiers at Snowbird. By 1700 all of the avalanche debris had been covered, finding only a ski pole and a mitten belonging to one of the two victims. With confidence now that no other victims had been buried in the avalanche, the rescue leader called off the rescue at this time.

Avalanche Data

Little Cloud is a north-northwest-facing slope in Gad Valley just below the ridge connecting Hidden Peak (where the tram unloads) and Twin Peaks. This avalanche was a SS-AS-4; it fractured 4 feet deep along a 150-foot-wide front and ran more than 2000 feet slope distance. The slope fractured a short distance below the large shot hole made by the 8-pound charge 4 hours earlier, indicating that this charge was probably placed too high for maximum effect.

The Little Cloud chute has a steepness of about 35° at its top. It had been lightly skied this ski season, and a thick layer of depth hoar had developed at the bottom of the snowpack.

Comments

There are many similarities between this accident and the one occurring 4 days earlier (No. 71-22). Both occurred on slopes that were very similar in elevation, steepness, and aspect. These slopes had seen only light numbers of skiers during the young ski season; hence, they had not been stabilized by skier traffic. Both of these accident sites had been hit with explosive charges and produced no avalanches on the morning of the accident.

The prime suspect in both of these post-control avalanches is the depth hoar within the snowpack. As shown by these two accidents, explosive control alone will not solve all depth-hoar problems. It is sometimes necessary—and desirable—to stabilize by using both explosives and ski traffic. The ski traffic provides stabilization through compaction of the new snow.

The winter of 1971-72 was Snowbird's first year of operation, and the area got off to a late opening. By late December, many of Snowbird's runs had seen very few skiers and, hence, had very little compaction. However, subsequent seasons have seen a large increase in the number of skiers at Snowbird. This has resulted in more ski compaction on many of its runs and a corresponding decrease in the chance of post-control avalanche release. In addition, the ski patrol has gained better information on avalanche release points, insuring more accurate shot placement.

APPENDIX 1

GLOSSARY

AIRBLAST: A strong rush of air produced in front of a fast-moving, powder avalanche. Potentially destructive.

ASPECT (or EXPOSURE): The direction in which a slope faces. A north-facing slope has a north aspect.

AVALANCHE: A mass of snow sliding down a mountain.

AVALANCHE CONTROL: Artificial means of releasing an avalanche or stabilizing the snowpack in place. Commonly used methods are protective skiing, test skiing, hand charges, and artillery.

AVALANCHE HAZARD: A threat to life and property from avalanches.

AVALANCHE PATH: The entire area down which an avalanche moves and made up of the starting zone, track, and runout zone. Also called SLIDE PATH.

AVALAUNCHER: A commercially available compressed-gas gun which launches an explosive projectile at a distant avalanche slope. Used for avalanche control.

BELAY: To secure (a climber or skier) by a rope held firm either by a fixed object or by another person.

BURIED: A category of the avalanche toll for an accident. A person is buried in an avalanche if he is completely beneath the snow when the avalanche stops. Persons with only a ski tip or a hand or foot protruding from the snow are considered to be buried. Persons in vehicles or buildings that are completely buried are considered to be buried. By definition, a person who is buried is also considered to be caught. Also see CAUGHT and PARTLY BURIED.

CAUGHT: A category of the avalanche toll for an accident. A person is considered caught in an avalanche if he is in any way involved in the moving snow. Also see BURIED and PARTLY BURIED.

CORNICE: An overhanging mass of snow forming from wind-drifted snow along the crest of a ridge. The steep slope below a cornice is often the starting zone for an avalanche.

CROWN FACE: See FRACTURE LINE.

DEBRIS (Avalanche Debris): A mass of snow, soil, rock, trees, etc., brought down by an avalanche.

DENSITY (of new snow): Mass per unit volumn of snow, expressed in g/cm^3 or kg/m^3. The density of water is 1 g/cm^3 or 1000 kg/m^3. Typical new snow densities range from .03 to .30 g/cm^3 (30 to 300 kg/m^3). See WATER EQUIVALENT also.

DEPTH HOAR: Large, coarse grains of snow formed by temperature gradient metamorphism within the snowpack. Depth-hoar grains have distinct faces and corners, sometimes appear as pyramids and cups, and can grow to a size of 10mm. Often growing just above the ground where the temperature gradient is largest, depth hoar forms a very weak layer which is highly susceptible to shear or collapse.

EXPOSURE: See ASPECT.

FALL LINE: The steepest or most direct path down a slope; the direction perpendicular to a contour line.

FRACTURE LINE: A well-defined line where the moving snow breaks away from the more stable snow above. Also called CROWN FACE.

HAND CHARGE: An explosive charge thrown by hand onto an avalanche slope. The desired effects are either to release the avalanche or to stabilize the snow in place.

HOWITZER (or PACK HOWITZER): A portable military artillery piece for firing an explosive round into a distant target. Both 75-mm pack howitzers and 105-mm howitzers are used for avalanche control.

INJURED: A category of the avalanche toll for an accident. Self-explanatory.

KILLED: A category of the avalanche toll for an accident. Self-explanatory.

LEE (side of a slope): The side sheltered or protected from the wind. An east-facing slope is in the lee of a west wind. Opposite of WINDWARD.

PARTLY BURIED: A category of the avalanche toll for an accident. A person is partly buried in an avalanche if he is covered by snow anywhere from the ankles to the neck when the avalanche stops. By definition, a person who is partly buried is also considered to be caught. See also CAUGHT and BURIED.

PROBE LINE: A line of rescuers, formed along a contour and facing uphill, organized to probe the snow with poles to locate an avalanche victim.

PROBE POLE: A lightweight metal pole used to penetrate the snow to locate an avalanche victim.

PROTECTIVE SKIING: Deliberate day-today skiing of avalanche slopes to stabilize the snowpack. The starting zone is cut several times in a criss-cross pattern to break up the slab. Protective skiing is ineffective and not recommended on hard slab. Compare with TEST SKIING.

RECOILLESS RIFLE: A military artillery piece, with severe backblast which eliminates recoil, for firing an explosive round into a distant target. Mounted either on a permanent platform or on the bed of a vehicle, both 75-mm and 105-mm rifles are used for avalanche control.

RUNOUT ZONE: The lowest part of an avalanche path where the avalanche debris stops because of a decrease in slope angle or a natural obstacle.

SHEAR: Stress applied to a body in such a way that equal and opposite forces are exerted on its ends along different lines of action, thereby tending to change the shape of the body without changing its volume. For example, shear stress will tend to deform a square-shaped body (viewed from the side) into a parallelogram-shaped body. In a snow slab, the slope-parallel component of gravity tends to pull the slab downhill while friction and cohesion between snow surfaces acts to hold the slab in place. Slippage between the slab and its undersurface can result, and failure can occur if shear stress exceeds shear strength. Compare with TENSION.

SLAB: A layer of snow characterized by internal cohesion between snow grains.

SLIDE PATH: See AVALANCHE PATH.

SLOPE DISTANCE: The length (of an avalanche) measured on or parallel to the surface of the ground.

STABILIZE: To compact the snow or relieve stress in the snowpack and thereby reduce the chance of avalanche release. Stabilization can occur naturally with time or can be effected with avalanche control.

STARTING ZONE: The area where an avalanche releases. Also called loading zone, catchment basin, release area, fracture zone.

STUDY PLOT: A site at which precipitation, temperature, and snow cover measurements are taken daily. These data are used with other measurements, such as wind, to estimate hazard.

TENSION: Stress applied to a body in such a way that equal and opposite forces acting away from each other are exerted on its ends along the same line of action, thereby tending to elongate the body. A snow slab is placed in tension by the slope-parallel component of gravity tending to pull the slab downhill while its anchor points and the cohesion between grains try to hold it in place. A slab can fail in tension when tensile stress exceeds tensile strength. Compare with SHEAR.

TEST SKIING: An attempt to release avalanches on selected small slopes by skiing across the normal fracture zones. Test skiing is used as an indicator of hazard buildup and the possible need for more control measures. Compare with PROTECTIVE SKIING.

TOE (of an avalanche): The tip of the avalanche debris after an avalanche has come to a stop. The toe marks the farthest extent of the sliding snow.

TRACK: The middle part of an avalanche path below the starting zone and above the runout zone.

TRANSITION (of a slope): A sharp change in the steepness of a slope. Going down the slope, a transition to a flatter area is called a *bench* or *step;* a transition to increased steepness is called a *roll, drop-off, cliff,* etc.

UNSTABLE (slab or snowpack): Near the point of failure; stress and strength of the slab are very nearly equal. Additional snow loading, an explosive charge, a skier, or the like could cause avalanche release.

VERTICAL FALL DISTANCE: The drop in elevation of an avalanche from the starting zone to the toe of the debris.

WATER EQUIVALENT: The liquid water content of a given amount of snow, measured in inches. Usually determined by weighing.

WINDWARD (side of a slope); The side facing into the wind. Opposite of LEE or LEEWARD.

APPENDIX 2

AVALANCHE CLASSIFICATION

The avalanche classification used in this volume is the standard avalanche classification used in the United States. Five elements of an avalanche are covered: type, trigger, size, sliding surface, and airblast, in that order.

Type; HS = hard slab, SS = soft slab, WS = wet slab, L = loose snow, WL = wet loose.

Two principal types of avalanches are recognized: loose snow and slab avalanches. *Loose-snow* avalanches are characterized by cohesionless snow; they originate from a point and fan outward as they flow downhill. *Slab* avalanches are characterized by cohesion between the snow grains; they originate from a well-defined line called a fracture line (or crown face). Slab avalanches are further subdivided into *soft-slab* and *hard-slab* avalanches, depending on the density and degree of cohesion of the snow. The distinction between soft slab and hard slab is often difficult to make. Usually, however, a soft-slab avalanche disintegrates into loose material while sliding downhill; a hard-slab avalanche contains large chunks or angular blocks of snow in the debris. The density of hard slab is usually $\geqslant .30$ (30% the density of water or .30 gm/cm^3 or 300 kg/m^3). Both loose-snow and slab avalanches are classified as *wet* if free water is present in the snowpack or if the debris is obviously refrozen when inspected several hours after the event.

Trigger: N = natural release; AS = Artificial, ski release; AE = artificial, hand charge (explosive); AA = artificial, artillery; AL = artificial, avalauncher; and AO = artificial, other, a miscellaneous category of artificial triggers which includes snowcats, snowmobiles, persons on foot, snowshoes, artillery backblast, etc.

Size: The size of an avalanche is designated with a number scale ranging from 1 to 5. A size 1 avalanche, or sluff, is any snowslide running less than 150 feet slope distance (approximately 75 to 100 feet vertical) regardless of its other dimensions such as width, fracture line, etc. All other avalanches are classified by a number 2 to 5 that designates their size, with larger numbers indicating larger sizes. This size classification is based on the concept that size should convey an estimate of the volume of snow that is transported down an avalanche path rather than an estimate of threat to life or property. In addition, sizes 2 to 5 are reported relative to the slide path. A "small" avalanche is one that is small (moves a small volume of snow down the path) for the particular avalanche path; a "large" avalanche is large (moves a large volume of snow down the path) for that path.

With these specifications in mind, the avalanche size classification becomes:

1 = a sluff, or snowslide less than 150 feet slope distance (approximately 75 to 100 feet vertical) regardless of volume of snow
2 = small, relative to the avalanche path
3 = medium
4 = large
5 = major or maximun

Sliding surface: O = an avalanche that ran on an old snow surface in the starting zone (surface avalanche); G = an avalanche that ran to the ground in the starting zone (ground avalanche).

Airblast: J indicates airblast, the potentially destructive strong wind that may extend well beyond the visible dust cloud or moving snowfront. Airblast occurs only with large, fast-moving avalanches.

Examples: SS-AS-2 = a small soft slab released by a skier; SS-AE-4-0-J = a large soft slab released by a hand charge, ran on old snow surface with airblast; HS-AO-3-G = a medium-size hard slab released by a miscellaneous artificial trigger, ran to the ground; L-N-1 = natural loose snow avalanche running less than 150 feet slope distance (a sluff).

APPENDIX 3

ON AVOIDING AND SURVIVING AVALANCHES

The accidents in *The Snowy Torrents* provide an excellent sample that identifies likely avalanche victims, shows how and why victims get themselves in trouble, and points out which activities may lead to avalanche encounters. Almost half the accidents (35 of 76) reported from 1967-71 occurred within ski areas; these included both recreational skiers and ski patrolmen. An additional 12 accidents involved ski tourers. Hence, approximately 60 percent of the accidents involved skiers, and assuming this ratio to be valid for the long term, skiers as a group are more likely to run afoul of avalanches than anyone else. (If one considers all the minor accidents that occur each winter but are not documented, the ratio of skiers to the total number of persons caught would be considerably higher than 60 percent.)

Climbers, hikers, and snowmobilers also are enthusiasts whose recreation may lead them into avalanche encounters. But persons not at play may also become avalanche victims, as shown by the accidents involving people at work, motorists, and occupants of homes or cabins.

The whole key to reaching these various interest groups and saving lives lies in public education. By drawing on the experience of others, this Appendix serves to increase avalanche awareness and prescribes rules of safety for avoiding and surviving avalanches.

Avoiding avalanches

The basic guidelines for avoiding avalanches are simple and involve only common sense and a little acquired knowledge and experience. Persons who expect to encounter avalanches in recreation or work should develop the skills to make a few elementary observations of evidence of avalanches and to evaluate snowpack stability, or know to whom to turn for such information. In short, they need to know when and where skiing, travel, work, etc., is safe in mountainous terrain.

1. Sources of avalanche information:

Information on current avalanche conditions is available from several sources. Contact local U.S. Forest Service or National Park Service offices and ski area patrols for the latest avalanche information; listen for weather reports over radio and television for the latest weather. In some parts of the country (the Rockies of Colorado, the Wasatch Range of Utah, and the Cascades of Washington), avalanche warnings are issued jointly by the Forest Service and National Weather Service. These warnings are broadcast over radio and television and provide the listener with information during dangerous periods.

When skiing within developed ski areas, the procedure for obtaining information is simple: ask the ski patrol which slopes are open and do not violate avalanche closure signs. There are an ample number of accidents (Nos. 68-8, 69-18, and 71-14 to name a few) to illustrate that avalanche closures are purposeful and to violate them is to invite trouble. (Ski areas, too, have a responsibility to the skiing public not to abuse avalanche closures by applying them at times when no avalanche hazard exists or at places where the reason for closure is other than avalanche hazard. Skiers will soon realize that the ski area is merely "crying wolf" with such closures and will no longer respect these closures.)

2. Identification of avalanche areas and dangerous conditions:

Safe travel outside ski areas requires a knowledge of terrain, weather, and stability evaluation. Avalanche paths are usually iden-

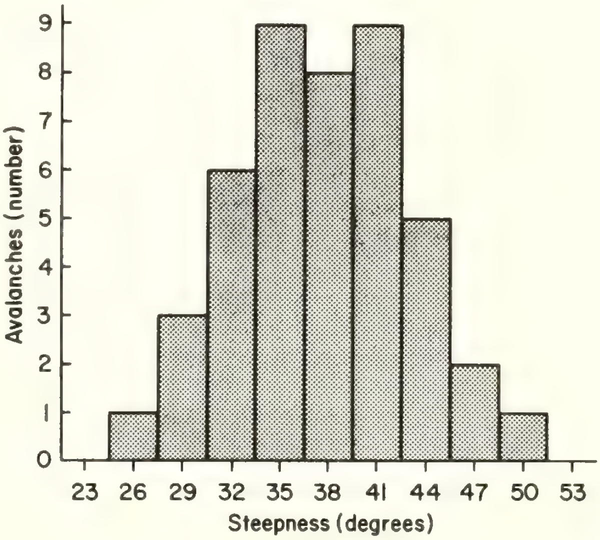


Figure 3.1. Frequency diagram of number of avalanches per 3-degree classes of starting zone steepness. Based on data from the accidents in this volume.

tifiable by avalanche debris, a trimline of trees along the edges of the path, bent-over trees, or damaged trees. A recent publication by M. Martinelli, Jr., *Snow avalanche sites: their identification and evaluation* (Agriculture Information Bulletin 360), contains many good photographs of avalanche paths and offers guidelines for identification. This publication is available from the Superintendent of Documents for 50 cents.

The best indication of instability (i.e., dangerous conditions) is recent avalanche activity. Other indications are hollow sounds beneath feet or skis (see No. 67-10 for example), collapse of the snow beneath the feet, and cracks in the snow shooting ahead and behind. "Talking" snow such as this is highly unstable.

3. Avalanches related to slope steepness and aspect:

There is a definite relationship between avalanche occurrence and slope steepness. Avalanches occur most frequently on slopes of 30° to 45°. Figure 3.1, based on the accidents in this volume, graphically reveals this fact. Snow-country travelers should bear this information in mind.

There is a much less definite relationship between avalanche occurrence and slope aspect. The avalanches in this volume do show a strong bias toward occurrence on north-facing slopes; however, about half of these accidents occurred in ski areas, and ski areas have predominantly north-facing slopes. If ski-area accidents are excluded from the sample, the back-country accidents show a more even distribution on all aspects. Accidents occurring on north and east exposures are only slightly more numerous than those occurring on south and west exposures. The important thing to remember here is that avalanches can release on slopes of all aspects. Especially when major storms are in progress, all slopes may be equally unstable.

4. Avalanches related to storms:

A most important point is that most avalanches, and consequently avalanche accidents, occur during or within 24 hours of a storm, and are thus called direct-action avalanches. Indeed, 85 percent of the accidents in this volume occurred during or after storms. It is also important to remember that storms need not be large to produce dangerous conditions; a few inches of snow with strong winds can produce dangerous slab conditions on lee slopes. Accident No. 69-4 is an example of such a "setup" condition. The moral is that one should be extra cautious if snow has fallen within 24 hours, especially if accompanied with strong winds. Unfortunately, good powder skiing and avalanches go hand-in-hand.

5. Route selection and safe travel:

There are few hard and fast rules of route selection when traveling in avalanche country. Whether on foot, snowshoes, skis, or snowmobiles, travelers are usually forced to choose a route that is a compromise between the more efficient (more direct, least exhausting, etc.) and the safest. It is best to avoid dangerous slopes altogether; this is done by staying on valley floors, ridgetops, slightly on the windward sides of ridges, or in dense timber. Often, however, it is necessary to cross a dangerous slope, and it is here that a few safety guidelines need be applied.

a. Initially, the decision must be made whether to cross, to alter the route, or to turn back. Signs of instability, wind slab, or heavy snow or rain indicate that the prudent decision is to turn back or alter the route.

b. If the crossing must be made, cross very high (above the normal starting zone) or very low (in the runout zone). Avoid traversing the starting zone or middle of the track. This is a common-sense application of avalanche awareness: when crossing the starting zone or mid-track, one runs a high risk of triggering the avalanche himself and getting caught; when crossing the runout, one only runs the risk of getting caught by a natural release from above.

c. If a starting zone must be traversed, cross as high as possible. Should the slope fracture, most of the sliding snow lies below the victim; thus he has a better chance of staying on the surface. A victim low on the slope is in a very poor position, as shown by numerous examples (Nos. 67-3, 68-9, 70-2 and 71-18 to name a few).

d. If a starting zone must be climbed or descended, keep far to the sides. Should the slope fracture, the victim has a better chance of bailing out to the side of the avalanche.

e. Cross an avalanche slope one person at a time, all other members of the party watching from a safe location. If the slope is especially wide, traversing members should be spaced several hundred feet apart. All persons should traverse in the same track. These precautions insure that if an avalanche releases, no more than one member of the party will be caught and all other members will be available as rescuers. It is not uncommon for the second, third, or even tenth member of a group skiing down or traversing a slope to be the one to trigger the avalanche (see Nos. 67-3, 68-9, 71-23 for example), so all members should exercise caution. By traversing in the same track, less snow is being disturbed, thus the chance of triggering the avalanche is minimized.

f. Use a climbing rope for belay when crossing an especially dangerous slope (one which offers no escape route and which may sweep the victim into a gully or crevice or over a cliff).

Safety measures and equipment

Persons who are exposed to avalanches from time to time can take several precautions in addition to common sense thinking and proper route selection to improve their chances if caught and buried. Before entering an avalanche slope, tighten all clothing, zipping up zippers and pulling cap on tight. This will insure some degree of warmth if buried. If carrying a heavy pack, loosen the shoulder straps or even sling the pack over one arm so that the pack can be easily shed if caught.

If on skis, remove the ski pole wrist straps so that poles can be thrown away. It will be much easier to swim with the avalanche if the hands are free. Removing ski safety straps is an arguable point that has both pros and cons. On the one hand, the avalanche victim wants first to ski to the edge of the slide if possible; having skis on is mandatory for this escape. Also, having skis still attached to a buried victim serves two purposes: first, there is the chance that a ski tip will protrude from the snow making for a quick rescue (No. 71-20 for example); and second, skis provide two more objects for probers to strike while searching for the victim (No. 67-1 for example). On the other hand, shedding skis makes it much easier for the victim to use his legs while swimming with the avalanche (No. 68-4 for example). Attached skis may also pull the victim to a deeper burial, as well as increase the chance of injury from a windmilling ski.

Of the equipment that one can carry with him, an avalanche rescue beacon such as a Skadi offers by far the best chance of a live recovery. To be effective, each member of a party must be equipped with one of these transceivers and must have received practice using them according to the directions supplied with each unit. The party must also be equipped with shovel (see below) for digging down quickly to a buried victim.

An avalanche cord is another safety device that should be employed. Accident No. 69-21 demonstrates its worth. The use of avalanche cords, however, is far from foolproof; the entire length of cord may be buried along with the victim (see Nos. 69-7 and 69-20).

Standard rescue equipment carried by back-country travelers should include probes and shovels. Ideally, each member of the party should carry a collapsible or sectional probe pole. At least one member of the party should carry a lightweight, collapsible shovel.

Surviving avalanches (if you are the victim)

While sitting back in an easy chair, it is easy to think calmly about the things an avalanche victim should do to help himself. In reality, however, a victim must try to make rational decisions all in a split second while at the same time fighting the panic that is natural to his situation. Experience may be a good teacher, but all too often a victim's first avalanche experience is his last. A person, however, can give himself a measure of safety by being in good physical shape to begin with, by committimg to memory some of the survival rules, and by anticipating trouble before entering a dangerous slope and having an escape route in mind.

Whether on foot, skis, or snowmobile, the victim's first move after being caught should be to try to escape to the side of the avalanche (or grab any tree that might be handy). This is more easily done if he can stay on his feet or machine. He should also be very conscious about clamping his mouth shut and breathing through his nose. Trying to gulp air through his mouth while submerged or partly submerged will only result in a mouthful of snow that becomes almost impossible to expel (see No. 68-4) and can hasten suffocation if completely buried.

If knocked off his feet, the victim should then put all his effort into swimming with the avalanche. The effectiveness of swimming has been documented throughout this volume (Nos. 67-3, 68-4, 68-9, 69-1, 69-21, 70-1, 71-12, and 71-23). A skier should rid himself of his ski poles (wrist straps should have been removed earlier) and begin swimming motions with his arms. He should also kick as best he can with his legs (if his skis have been ripped off, this will be easier). If the victim has been thrown forward and is being carried headfirst downhill, a breast stroke with the arms seems to be effective (see No. 68-9). If he is being carried feet first downhill, he should try to roll onto his back and attempt to "tread water" with his arms and legs (see Nos. 67-3 and 69-21). With these motions, the victim has some control over his depth and direction of movement in the avalanche. (If, however, the avalanche is large and turbulent, the victim will probably be rendered helpless.)

When the avalanche begins to slow to a halt, the victim should make every effort to reach the surface by thrusting upward with swimming motions. He should try to place one or both hands in front of his face and move his head and arms back and forth to create a breathing space before the slide has stopped. This may be very difficult to do but can be a lifesaving effort (see Nos. 67-1, 68-9, 70-3, 71-5, and 71-22). Another lifesaving gesture is to thrust upward with one hand (or ski pole) in an effort to break through to the surface. Accident Nos. 67-9, 68-9, and 70-3 demonstrate the value of this action.

If the buried victim can move in any way, he should do so to improve his position. If he is oriented so that he knows up from down or can see a hint of daylight, he should work toward reaching the surface. If he is completely pinned, he should try to stay calm, conserving his breath and energy, and await his rescuers.

Rescue (if you are the survivor)

The survivors of, or eyewitnesses to, an accident need to act quickly and with authority, for their actions over the next several minutes may mean the difference between life or death for the victim. They should first mark the last-seen point of the victim and begin their search directly downhill from that point. Use the avalanche rescue beacon if the victim was so equipped. Otherwise, work downhill quickly, searching for clues and scuffing and probing the snow with probes, skis, and ski poles.

If the accident occurred in or very near a ski area, one of the rescuers should notify the ski patrol immediately, for a large body of rescuers is available only minutes away. If the accident occurred in the backcountry, all rescuers should search and probe the area as thoroughly as possible before sending for outside help, which probably lies several hours away.

Rescuers need to familiarize themselves with the statistics of Appendix 4, especially noting that after a burial of only 30 minutes, a victim's chance of survival falls below 50 percent. Time is, therefore, of the essence in all avalanche rescues. Rescuers should also be fully aware, however, that fortunate circumstances can allow the victim many hours of life (see No. 67-2 for example). Thus, never abandon a rescue prematurely; give the victim every possible chance.

APPENDIX 4

THE DEADLY STATISTICS OF AVALANCHE BURIALS

A sample of 121 avalanche burials has been compiled from documented accidents from 1910 to 1974. This includes accidents from this volume, from the original *The Snowy Torrents*, and from 1972 to 1974. The purpose here is to determine the diminishing probability of survival with time; i.e., just how long can a buried avalanche victim be expected to live?

The answer to this question depends on many factors—injury, depth of burial, snow density, position of the victim, presence of airspace, size of airspace, etc. The combinations are almost endless, and it is these factors that determine whether a victim lives for several hours or dies within a few short minutes. A victim's rescuers cannot know which factors are at work in any given burial, so they must be aware of the cold, hard statistics of survival based on a large number of cases.

Figure 4.1 plots the 121 cases on a graph of depth vs. burial time. All victims included were completely buried, with the exception of a few cases where a ski tip, pole, hand, or foot was visible. But even in these cases, the victim's head was buried beneath the snow, he was unable to dig himself out, and his survival depended on a quick rescue. No victims buried in the wreckage of buildings or in vehicles are included in this sample for the reason that such victims can be shielded from the snow to allow sizable airspaces. The sample is, therefore, not biased by this extreme circumstance. (Colin Fraser in his book *The Avalanche Enigma* recounts the saga of a young Austrian man who survived a burial of 12½ days in the ruins of a small hut.)

Of principal interest in Figure 4.1 is that only 39 of 121 victims survived; hence, a completely buried victim has one chance in three of survival, regardless of all other considerations. Two points of further interest are that

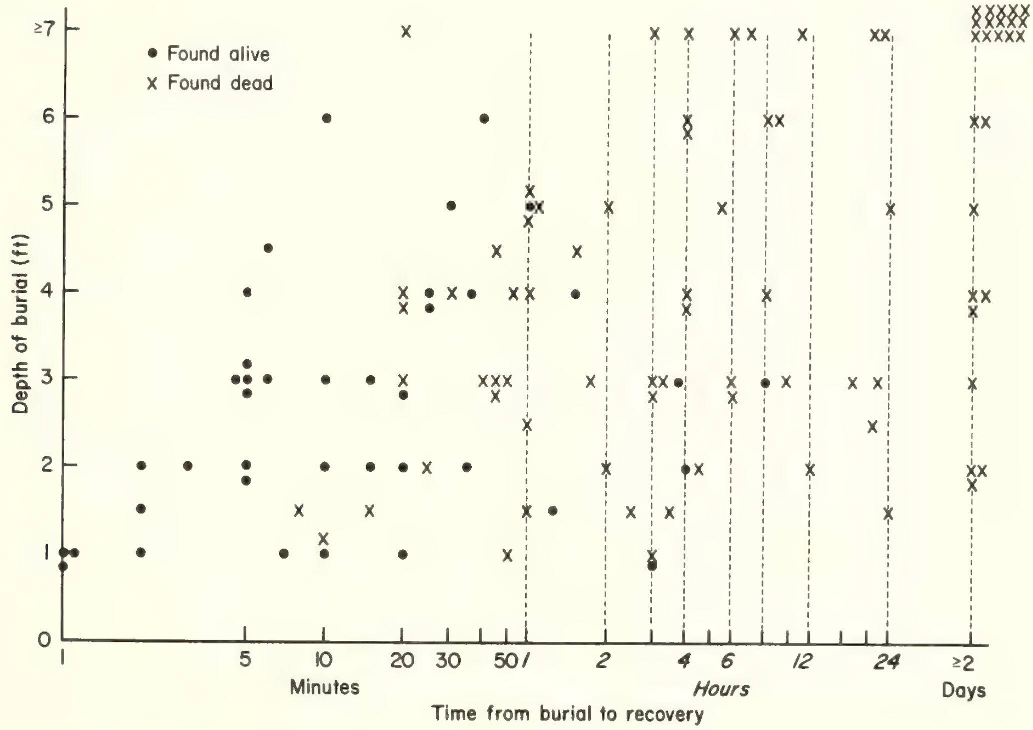


Figure 4.1. 121 buried victims of avalanches plotted on a graph of depth of burial vs. elapsed time from burial to recovery. Based on a sample of avalanche accidents in the U. S. from 1910-74. A solid dot indicates the victim was found alive; an X indicates the victim was found dead.

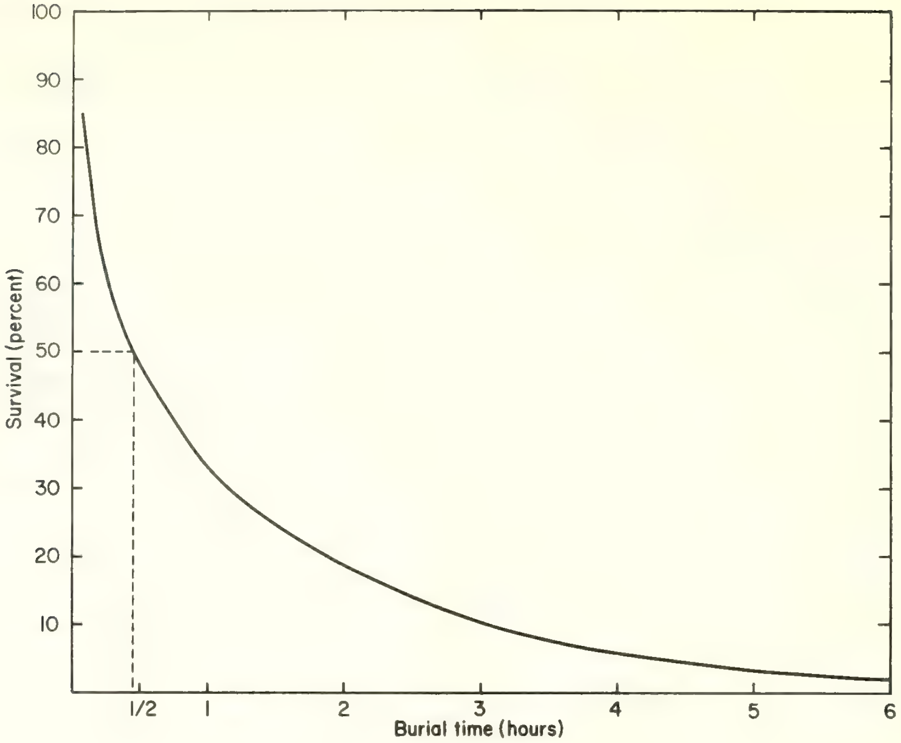


Figure 4.2. Percent survival among avalanche victims vs. elapsed time of burial. Based on a sample af avalanche accidents in the U. S. from 1910-74. Note that the 50% survival time is about ½ hour (30 minutes).

no victim survived a burial deeper than 6 feet and that no one was recovered alive after being buried more than 8 hours. These, then, are the limits of the "life zone" in this sample. *

The crucial figure derived from the data, however, is Figure 4.2. This gives the harsh statistics relating chance of survival to burial time. Take a look at this figure, especially noting that *the median or 50% survival time is about 30 minutes*. In other words, after a burial of 30 minutes, only 50 percent of the victims can be expected to survive. The message is clear: *time is of essence in avalanche rescue*. Rescuers must be keyed in to this fact.

A number of years ago, the time limit for 50 percent survival was believed to be about 2 hours. Rescues were planned accordingly, with efforts to locate the victim in 2 hours or less. In 1968, the U.S. Forest Service published *Modern Avalanche Rescue* which revised the time limit for 50 percent survival down to 1 hour. To meet this goal, a three-stage rescue was proposed, with emphasis on speed for the first two stages.

Now, however, the statistics reveal the 30-minute time limit. This has strong implications on avalanche rescues both within ski areas and without, the burden of speed being more important than ever. The three-stage rescue for organized units, as proposed in *Modern Avalanche Rescue*, can be made to meet this deadline. Stronger emphasis, however, is placed on the hasty search unit (stage 1) than before. This group must have adequate manpower and equipment to perform an initial hasty search and probe, all within a shorter time span than ever before. For backcountry rescues, the message is clear and blunt: *virtually the only chance a buried victim has to live is to be found by his compan-*

---

*There are several documented cases that have occurred outside the United States in which victims buried completely and in direct contact with the snow have survived for more than 8 hours. One remarkable case occurred in January 1960 near Invermore, British Columbia, Canada. James Duke, 59, a Department of Highways employee, was swept away and buried while acting as an avalanche lookout for a work crew. Defying all odds, he was found alive 25½ hours later beneath 5 feet of snow. An airspace the "size of a washtub" around his head saved his life.

ions. The necessity of seeking outside rescue units in effect assumes that a dead recovery is all that can be expected. Thus, back-country travelers should always be prepared for such emergencies. Avalanche rescue beacons (such as Skadis) or collapsible probe poles are mandatory equipment for back-country trips that intersect avalanche terrain.

These are very sober thoughts, but thoughts that must be realized by back-country travelers and rescuers alike. A further thought, however, is that rescuers must never abandon their search prematurely. Figure 4.2 shows that even after 6 hours, approximately 2 to 3 percent of the victims, or about 1 in 40, can be expected to be found alive, and no avalanche victim should ever be denied this small chance at life.

APPENDIX 5

AVALANCHE ACCIDENT REPORTING FORM
(Attach additional pages whenever needed)

I. General information

1. Date:____________________ 2. Time of accident:____________________

3. Exact location:

4. Victim(s)

Name	**Age**	**Address & Phone**	**Conditions/injuries**

5. Eyewitnesses or other members of party

Name	**Age**	**Address & Phone**

6. Damage to vehicles, buildings, lifts, etc. (Itemize and give dollar estimate of loss)

II. Accident summary

1. Events leading up to accident (General description of circumstances and events including objective of party, departure point, route taken, etc.)

2. Accident account (Eyewitness account or observer's deductions based on tracks and other evidence. Important points are: how slide was released, location of victim(s) at release, last seen point, etc.)

III. Rescue (Time and names are important)

1. Time report of accident received and from whom:____________________

2. Hasty party

Time dispatched:________________ Leader's name:________________

Number in party:________________ Time arrived at site:________________

3. Followup (main) party

Time dispatched:________________ Leader's name:________________

Number in party:________________ Time arrived at site:______________

4. Description of search procedures (including location of clues, etc.):

5. Time, location, and position of victim(s) when found:

6. Depth of victim(s), length of time buried, condition and injuries:

7. Cause of injury or death (For fatalities, include coroner's report, if available):

8. Time rescue was concluded:____________________

9. Other pertinent information:

IV. Weather and snowpack data

1. Weather synopsis (include instrument data readings when available):

2. Snowpack structure:

3. Were warnings, restrictions, or closures in effect?

V. Avalanche data

1. Type of slide (classification):________________

2. Dimensions: width________________; length (indicate either vertical or slope distance)________________

3. Fracture line: depth________________ length________________

4. Depth of debris:________________

5. Other pertinent information: ____

VI. Terrain data

1. Elevation:____________________ 2. Aspect: ____________________

3. Starting zone slope angle in degrees: ____________________
(Add "M" if measured, "E" if estimated)

4. Vegetative cover (open, timbered, etc.): ____________________

5. Shape of path (open slope, gully, etc.): ____________________

VII. Conclusions (cause of accident, etc.) and recommendations:

Signed ____________________

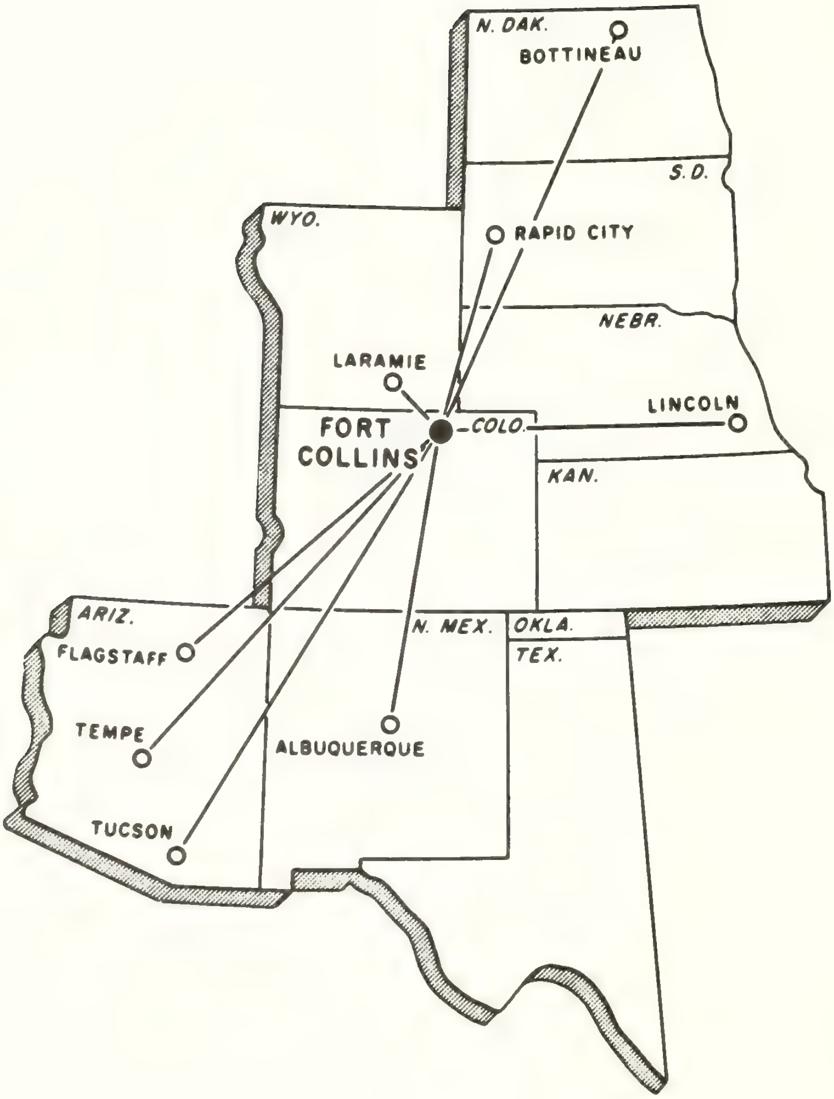
Address ____________________

____

____

The following attachments should be included whenever possible:

1. A full narrative summary of the accident and rescue.
2. A vicinity map showing location of accident relative to the nearest town or landmark.
3. A detailed map or diagram with scale, legend, and north direction arrow and showing slide area, fracture line, deposition zone, landmarks, victim's (and others) route, positions of all persons at time of accident, last seen point(s), location of clues, area probed, where victim(s) found, and location of closure signs (if applicable).
4. First-person statements of survivors or eyewitnesses.
5. Photos.
6. Newspaper stories.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Avalanche Protection In Switzerland

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General Technical Report RM-9
March 1975

U.S. Department of Agriculture. Forest Service.
1975. Avalanche protection in Switzerland [Lawinenschutz in der Schweiz, translated by U.S. Army, CRREL]. USDA For. Serv. Gen. Tech. Rep. RM-9, 168 p. Rocky Mt. For. And Range Exp. Stn., Fort Collins, Colo. 80521.

This translation of a collection of 16 articles by Swiss avalanche experts summarizes the current state-of-the-art of structural control of avalanches in Europe. It includes articles on avalanche formation, damage, and protective measures, and supporting, deflecting, and retarding structures.

Front Cover. Schiahorn/Davos: supporting structures on the left, Dorftaeli retarding and catchment structures in the middle of the picture (photo E. Wengi).

ACKNOWLEDGMENTS

We sincerely thank Mr. G. Bavier, President Administrative Commission and the editors of "Buendnerwald" for permission to translate this series of articles into English. We also want to thank Dr. M. de Quervain, Director Swiss Federal Institute for Snow and Avalanche Research (SLF), for his help contacting the proper organizations and individuals to gain this permission. U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) provided a preliminary English translation which in a few cases was reviewed by the original authors. Mr. Hans Frutiger of the SLF reviewed the English version of his article and provided many helpful suggestions. Dr. Hans Keller, on educational leave in Fort Collins from the Swiss Forest Research Institute, was of great help with many technical terms and in smoothing the English. Mr. E. Wengi of the SLF kindly furnished extra prints of several key photographs including the front cover picture. Any errors or inconsistencies that still exist in spite of the above help remain my responsibility.

M. MARTINELLI, JR.
Project Leader
Alpine Snow and Avalanche Research

AVALANCHE PROTECTION IN SWITZERLAND (LAWINENSCHUTZ IN DER SCHWEIZ)

[Supplement No. 9 to Buendnerwald, journal of the Braubuenden Foresters Association and of SELVA, Association of Graubuenden Wood Producers, German, December 1972]

The administrative commission of the technical journal Buendnerwald takes special pleasure in issuing this supplement "Avalanche Protection in Switzerland." An ad hoc editorial commission, consisting of forestry engineers F. Castelberg, H. R. in der Gand, F. Pfister, and B. Rageth, and the undersigned have striven to present the entire complex area of avalanche protection as comprehensively and clearly as possible. Publication of the supplement would not have been possible without the intensive cooperation of the Federal Institute for Snow and Avalanche Research, Weissfluhjoch-Davos, or without the substantial financial support provided by the Swiss Foundation for the Promotion of Forests and Wood Research in the Canton of Graubuenden.

All those who have cooperated in any way in preparing and publishing this supplement merit our warmest thanks.

Chur, December 1972

Buendnerwald Administrative
Commission
The President:
G. Bavier

FOREWORD

The first prerequisite for settlement of a mountainous region is the protection of its communities and transportation facilities against more or less predictable and recurrent catastrophes. As the most important of these preventive and protective measures, avalanche defense continuously acquires increased significance. Both the maintenance of individual mountain communities and the development of entire valleys in the alpine area depend upon it. From the total economic point of view, avalanche construction represents more than merely a local protective device: it is a part of the infrastructure of the mountain region and has become a sort of social security for the mountain population. Does not everyone have a right to minimal protection in his living space? Avalanche defense is a duty of the community.

As a result of the rapid development of travel from abroad and winter sports activities, avalanche control has become even more important. More and more people are entering into regions exposed to avalanche risk or into their vicinity. Fundamentally, it is man himself who increases the risks in his environment and endangers his own safety. Apart from periodic variations, the number of avalanches is not increasing but rather it is the number of risk-exposed people; and at the same time we are becoming more demanding with respect to our personal safety.

Avalanche control is not only the concern of the professional specialist; he himself must work in cooperation with the population and with the authorities. The latter must approve and finance projects. On the other hand these projects are a constituent of local and regional planning. They influence the utilization of ground space. Information, public education, together with mutual understanding and cooperation on the part of all participants are prerequisites of success in any undertaking. Furtherance of such interplay of a broad public is the task and at the same time the reward of this supplement to Buendnerwald, which is not directed just toward the forester and forest owner.

We here extend our thanks to the specialists in avalanche control who try to carry out their often dangerous task on steep slopes, precipices, and overhanging rocks near the upper tree line, unobserved, in a spirit of modesty and self-sacrifice.

Bern, December 1972

M. de Coulon
Chief Federal
Forest Inspector

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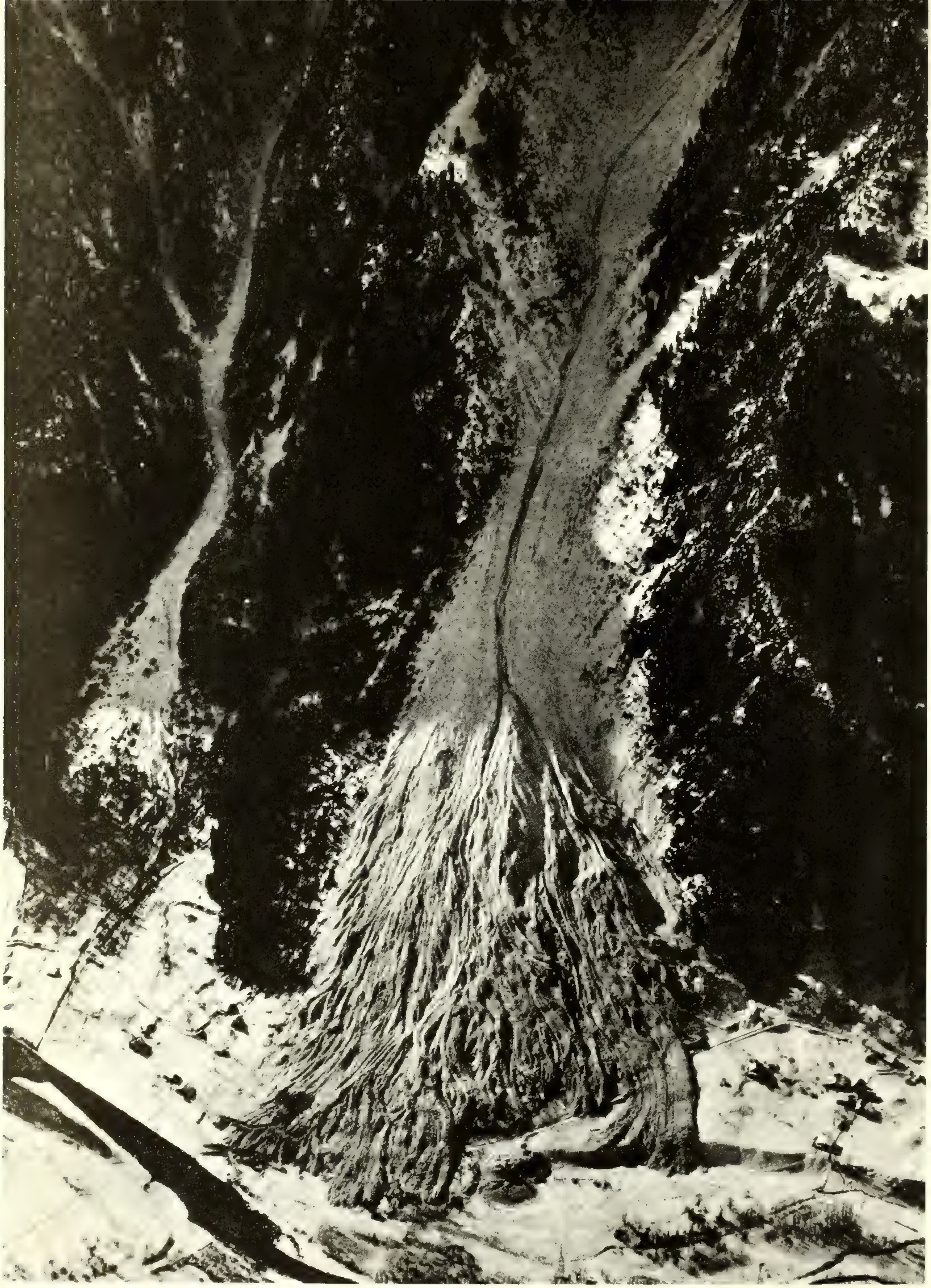

Figure 1.

I. AVALANCHE DAMAGE

(Karl Breu, Switzerland)

1. Introduction

J. Coaz, the Old Master of avalanche control, in his book Avalanches in the Swiss Alps, Bern, 1881, describes avalanche damage as follows: "The damage produced by avalanches consists essentially in tearing up rock and soil, in destruction of grazing lands and forests, of structures, enclosed areas, roads, and finally in the endangerment of men and animals." There is little to add to this enumeration and there would probably be little advantage in classifying here the possible varieties of damage.

Probably of more interest would be:

--the description of episodes of damage,
--the numerical evaluation of damage,
--the investigation of causes,
--conclusions.

2. Examples of Destructive Avalanches

2.1 Wilerlaui Near Silenen in the Cantons of Uri, Unterwalden

(Figure 1, photo W. Friedli)

The avalanche came down on 27 January 1968 at about 0610 hours. The avalanche debris cone was 500-600 m wide at the end of the tongue. The snow masses lay in part up to a height of 10 m. The avalanche swept away a dwelling and a stable. A farmer lost his wife and all five children, the neighboring family lost its breadwinner. The picture shows clearly that other buildings of the Weiler Rueti have been severely damaged. The Wilerlaui avalanche comes down several times every winter into the valley without doing any great damage. In 1968 it came down with such force that there was no more room for it in the avalanche track and it pressed up over the edges of the channelized track.

2.2 Motta Avalanche in Partenen, Montafon (Figure 2, photo Illwerk, Vorarlberg)

The avalanche came down on 27 January 1968 at 1058 hours. A fir log (diameter 50 cm) penetrated the house in the second floor along its entire width, penetrated the outer wall (wall thickness 43 cm) into the children's room, broke through the center wall (wall thickness 20 cm), then crossed the adjacent parents' bedroom, broke through the valleyside outer wall (wall thickness 43 cm) and extended 2 m in addition above the outer wall. The outer walls consisted of brickwork. The avalanche destroyed centuries-old alpine huts and forests lying in its path. One house was completely destroyed, five houses severely damaged, and three houses slightly damaged. There were no personal injuries since the inhabitants had been promptly evacuated.

2.3 Dorfbach Avalanche Davos

(Figure 3, photo E. Wengi)

The avalanche came down on 26 January 1968 at 2240 hours from the east flank of the Schiahorn. In the late afternoon of the 26th of January the local authorities ordered evacuation of a part of the Egga and Boedenhaeuser. It was thanks to these measures that no more persons were injured. Four persons were killed, nine houses and two garages totally destroyed as well as a bridge of the DPB and a crane and transport car of the Davos-Parsenn railway. Twenty additional houses were damaged. From 1956 on, several dwelling houses had been built in the area on the Egga and in the Boeden. An avalanche of this magnitude was a surprise to everyone. At the steep edges of the Dorfbach Gorge, to a point high up the mountain, old larch trees and firs were dragged along and the iron bridge of the Parsenn railway carried for a distance of nearly 300 m.

2.4 Forest-Destructive Avalanche of Vinadi, Lower Engadin

(Figure 4, photo Military Aviation Service)

The avalanche descended in the forenoon of 18 February 1962 from the ESE flanks of Piz Mundin and Piz Alpetta. In three arms it poured into the Inn [River] which lay about 2,000 m further down. The 120- to 130-year-old highland forest suffered total destruction of 90 to 100 hectares. About 20,000 m^3 of timber were knocked down. Additional damage occurred on the Austrian side of the Inn. It apparently involved the worst known instance of forest

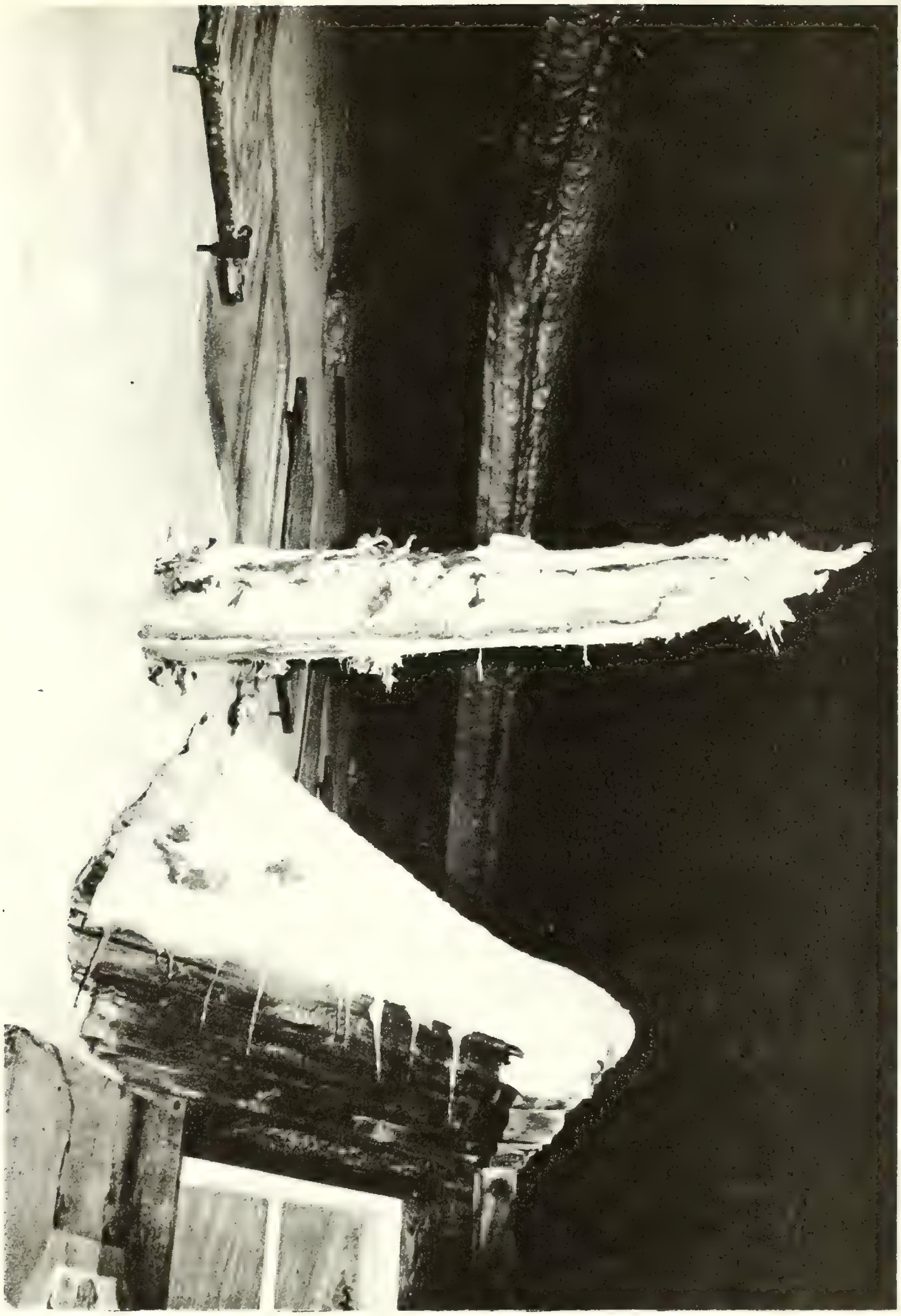

Figure 2.

destruction caused by an avalanche. The national highway was closed for several months.

The length of the avalanche along the slope was about 3.6 km, the mean width 1.5 km. The area was about 5.5 km^2.

2.5 Vallascia Avalanche, Airolo
(Figure 5, photo A. Roch)

The Vallascia avalanche, on the 12th of February 1951, 0045 hours, drove into the hamlet of Airolo with a deep rumbling, cracking,

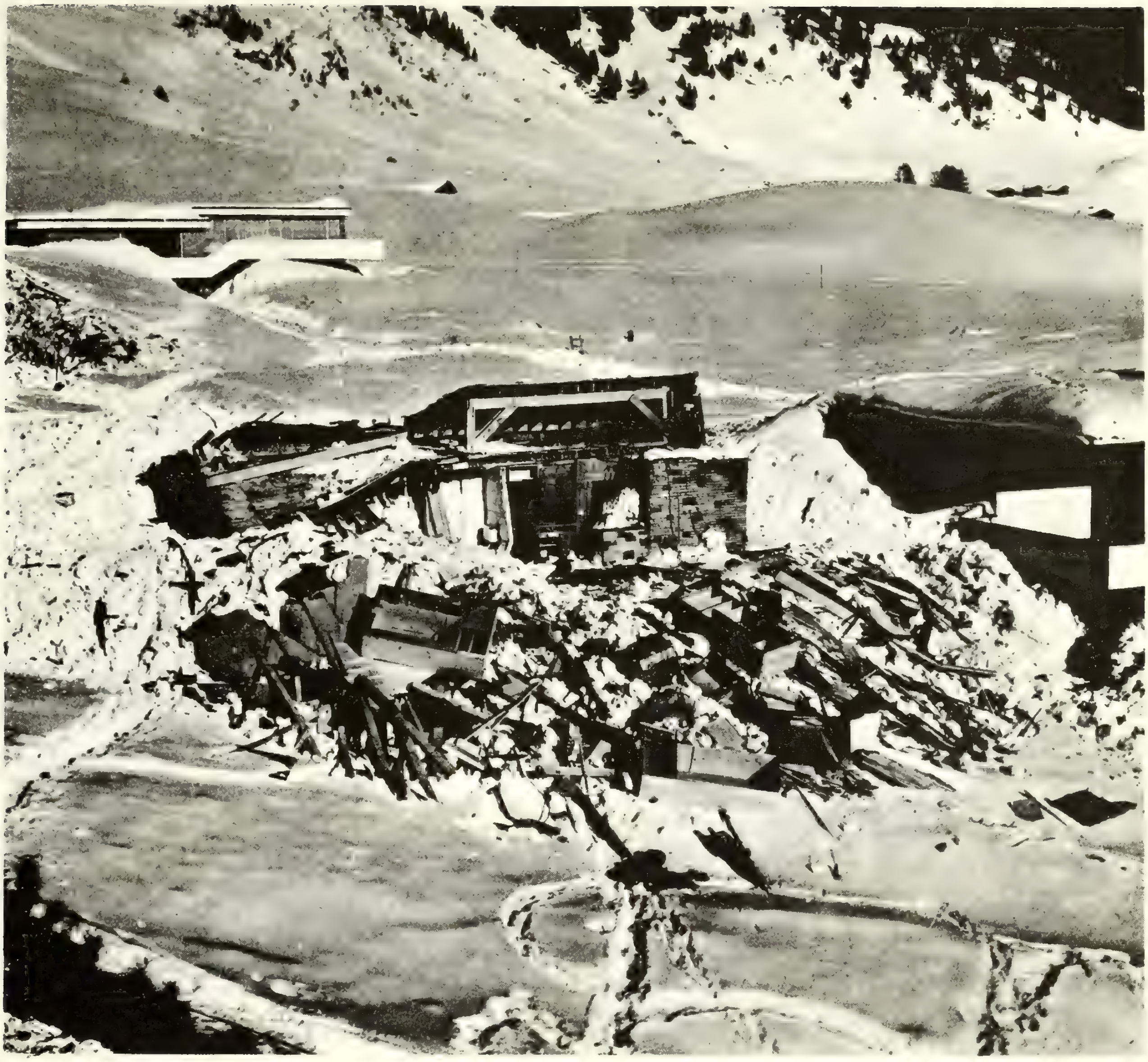

Figure 3.

and crashing. Eleven houses, 11 stables, and a cabinetmaker's workshop were totally buried and an additional seven houses were partially buried. Of the 15 persons buried, 10 were recovered dead. Previously, the avalanche danger had been thought to be slight because the avalanches descending from the steep slopes of the Corna del Buco and from the Vallascia region seldom reached the hamlet. Only once, in the year 1923, had the Vallascia avalanche produced greater material damage.

3. Avalanche Damage Statistics

3.1 Deaths and Injuries

In the 30 winters from 1940/41 to 1969/70, there were 743 deaths [from this cause] in Switzerland. This is an average of 25 deaths per year. In the same period, 392 persons were injured. That is an average of 13 persons per year.

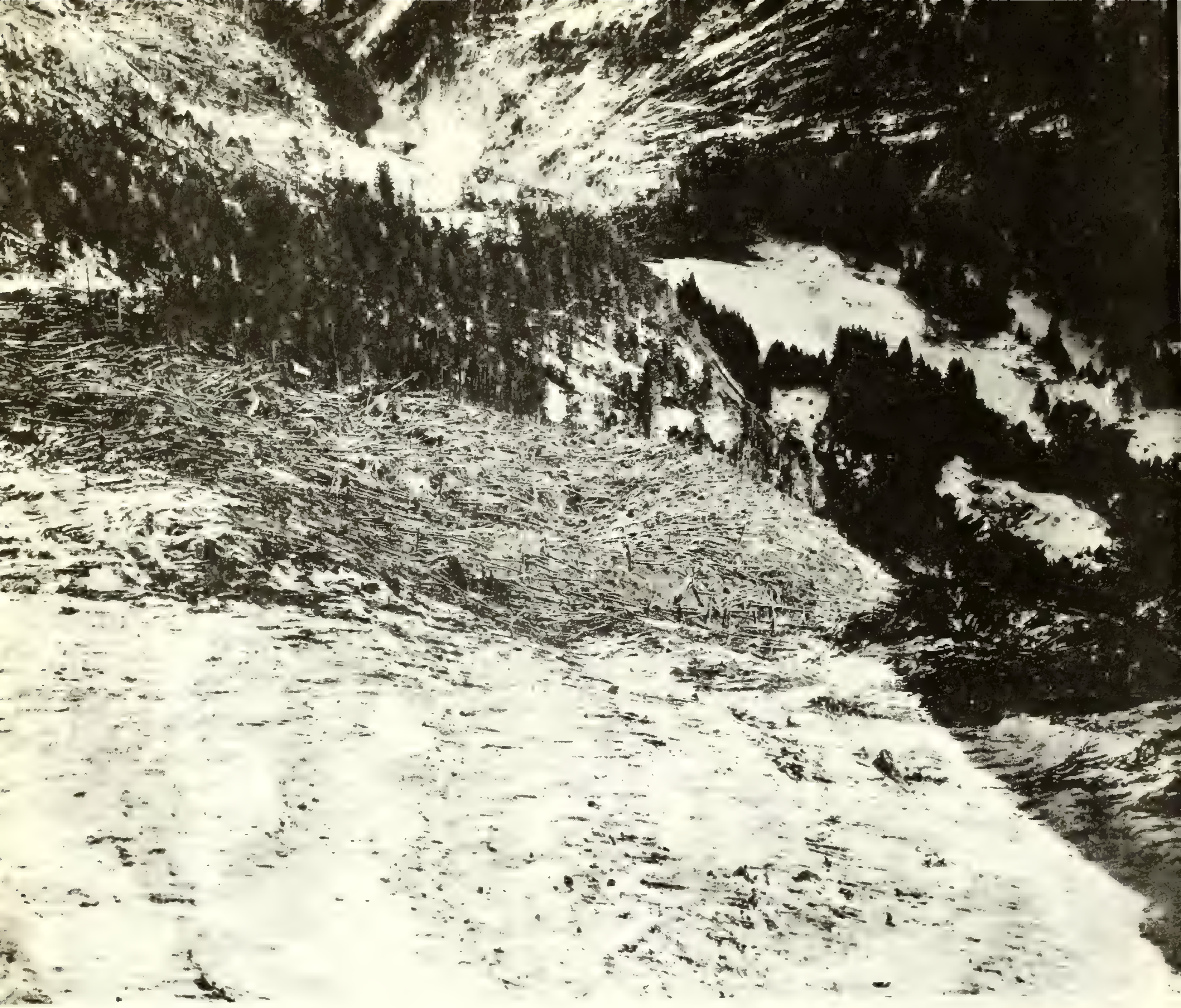

Figure 4.

In recent years, there has been a clear increase in avalanche accidents affecting skiers. As a result of increased opening up of the Alps and of the lower Alps, ever greater numbers of people are entering the mountains.

3.2 Damage to Buildings

In the 20 winters from 1950/51 to 1969/70, 403 houses were destroyed or damaged and in addition, 1,847 stables, hay-shacks, and alpine buildings.

3.3 Forests and Land Damage

In the 20 winters from 1950/51 to 1969/70 in Switzerland, around 2,550 hectares of forest were destroyed by avalanches. This is on the average of 120 hectares per year. The area of devastated alpine grazing land and meadows was probably about the same size.

3.4 Damage to Transportation Arteries

The damage to transportation arteries has been very great. There is first of all the cost of removing avalanche snow and of somewhat less significance is the damage to the roads and bridges. Even the most important north-south connection, the Gotthard road has not yet been rendered safe from avalanches.

3.5 Material Damage in the Avalanche Disaster in Reckingen

The material damage in the Reckingen avalanche disaster (27 February 1970) is given as 12.8 million francs not including personal damage. If we add to this the costs of necessary building, we get about 20 million francs without including personal damage.

3.6 Secondary Damage Caused by Avalanches

The accumulation of avalanche snow in streams can cause flow obstructions leading to water damage. Such a case occurred in the winter of 1963/64 in Bisisthal SZ, where the Muota washed out a street producing damage of 40,000 francs. The danger is particularly great in the case of streams which carry water only sporadically because of the presence of power plants.

3.7 Summary

For the period 1950/51 to 1969/70, avalanche damage can be estimated in terms of present monetary values, without including personal damage, but at the same time, including the cost of rescues, at an average of about 10 million francs per year. This figure includes damage to avalanche control measures but not the cost of new control measures.

4. The Causes of Avalanche Damage

Primarily, avalanche damage is caused by terrain and climate. Deforestation near the upper tree line, before the forest legislation came into effect, also definitely led to the formation of avalanche paths. In recent times, the dangers resulting from mass tourism (construction of houses in avalanche areas and increasing access to the mountains) must be added to the avalanche danger which was always present in the mountains. One cannot make a blanket condemnation of this development. Instead it must be controlled by means of suitable measures.

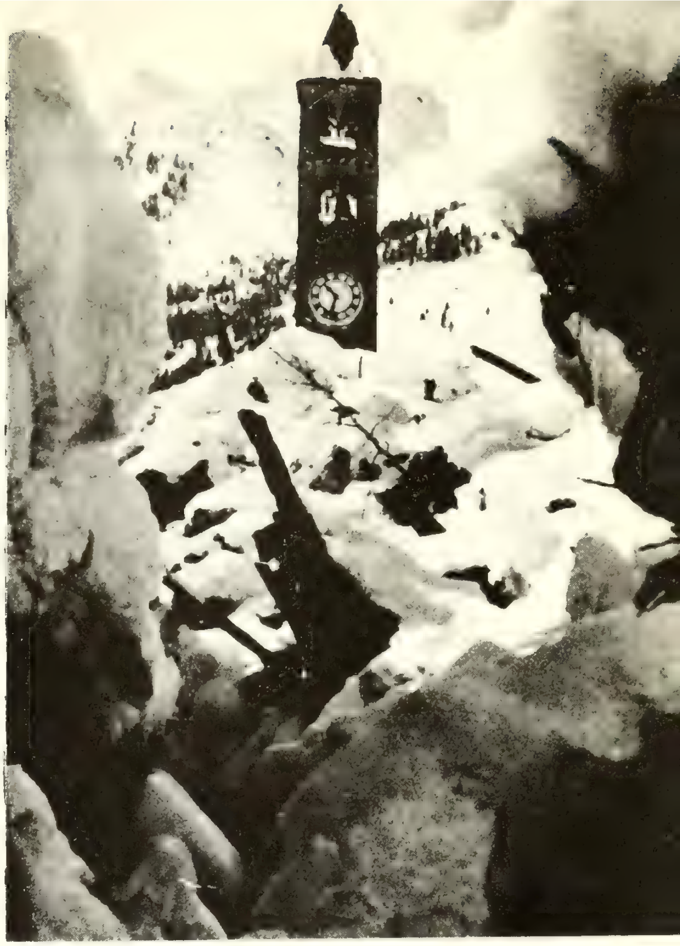

Figure 5.

5. Conclusions

The damage resulting from avalanches can be very great. Hence the great significance attached to protective measures. In spite of all efforts, avalanche damage cannot ever be entirely avoided. But, at an increasing cost, it must be reduced as much as possible because it continues to be true that "an ounce of prevention is worth a pound of cure."

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English Translation of German Titles

[1] The Avalanches of the Swiss Alps.
[2] Snow and Avalanches in the Swiss Alps.

II. AVALANCHE FORMATION (Marcel de Quervain, Weissfluhjoch/Davos)

1. Introduction

Basically two types of avalanche accidents must be distinguished: a human being, in his domicile or while moving about in settled or opened zones, can be surprised and buried by an avalanche breaking in upon him from high up above or, as a mountain climber, he may enter a dangerous starting zone and himself (generally) trigger the fatal avalanche. One distinguishes these two categories of disastrous avalanches -- or just plain "avalanche," without qualification -- as "catastrophic avalanches" and "touristic avalanches." These designations establish certain focal points; however, they are not always appropriate. Thus, in a period of heavy avalanche catastrophes, there are usually also minor avalanche descents into settled zones, while on the other hand touristic accidents may present catastrophic dimensions. In addition, among the "tourists" who get into avalanche emergencies, there are always the people who are patrolling avalanche-endangered terrain in the course of their professional duties.

Nevertheless, the distinction between these two types of accidents or avalanche situations is logical and useful since these situations generally occur separately with respect to time and place. When the conditions for great valley avalanches begin to ripen, the tourists have usually vanished from the starting zone regions since it is no longer possible to move about. On the other hand, it is precisely when snow is scanty (a time when large avalanches are out of the question) that experience has shown touristic accidents to be numerous.

In the following studies, the emphasis will be placed upon the origin of "catastrophic avalanches" since avalanche control concerns itself predominantly with this category.

2. The Snow Cover and Its Qualitative Development

Although catastrophic avalanche episodes are usually directly connected with heavy snowfalls, the condition of the old snow cover (and thus the entire winter starting with the first snow) plays a role. First we shall glance at the characteristics of new snow. It forms and falls under the most varied weather conditions: at air temperature that ranges (on the ground) from about -30° to $+5^{\circ}$, and at wind velocities from 0 to around 200 km/hr.

Wind turbulence leads to fragmentation of the original new snow crystals consisting of snow stars, platelets, needles, or irregular figures. Hence, the layered new snow can display a highly variable consistency from the outset, ranging from the lightest, fluffy, toothed, wild snow to brittle, fine-grained, stiff snow. Its density varies between 30 and 250 kg/m^3.

A rare type of snow appears on the surface after clear cold nights, namely flat crystals, often in a rosette arrangement. This is surface hoar which accumulates directly on the snow cover and in the course of a few days in shady hollows can develop into layers of several centimeters thickness.

Immediately after it deposits, new snow (especially the fluffy material at temperatures below 0°) undergoes so-called decomposition transformation [equi-temperature metamorphism].[1/] The substance first becomes felty and then round-grained and at the same time progressively increases in density (setting). The process is especially marked at temperatures slightly below the freezing point.

Independent of this and often progressing simultaneously, there is a constructive transformation [temperature-gradient metamorphism]. It is characterized by a general growth of selected snow grains with a change in their shape tending toward edged, planar forms. Reentrant angles and peculiar stepped surfaces appear, occasionally cup-shaped, hollow structures. In its final stage, such

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[1/] Decomposition transformation and constructive transformation are direct translations. These used to be referred to in English as destructive and constructive metamorphism. Now the processes are called equi-temperature metamorphism [ET metamorphism] and temperature gradient metamorphism [TG metamorphism]. The latter terms will be used in this translation.

snow is called depth hoar or sugar snow. TG metamorphism is a consequence of a temperature drop in the snow and presupposes air permeability. Ice sublimates from warmer snow particles and condenses on neighboring colder particles so that the latter grow at expense of the former.

If snow is warmed by warm air or by radiation to the point of melting and is subsequently cooled again, it is transformed into a round-grained adhesive material (melting transformation [melt-freeze metamorphism], formation of glacial ice). Figure 1 shows the three types of metamorphism.

Normally, the snow surface is colder than deeper snow layers. And after clear nights, it is even substantially colder than the adjacent air -- a fact which is understandable only on the assumption of invisible radiation. In response to the temperature changes, the surface layer is subjected to a marked transformation and in the depth of winter takes on a powdery consistency. After a further snowfall, the old loose surface layer remains in the interior of the snow cover and prevents binding between new and old snow. The separation is particularly clear when snow falls on surface hoar. In great snowfalls, superimposed layers undergo only slight TG metamorphism. They remain fine-grained and under the snow cover burden attain densities of over 500 kg/m^3.

The various types of snow as they are characterized by the nature and degree of their metamorphism have highly variable mechanical properties. Among these is the material strength (shearing, tensile, and compressive strength) which attains maximum values of about 200 kg/dm^2 (tensile strength) in fine-grained layers which have undergone predominantly ET metamorphism. Lowest and barely measurable material strength values are attained in loose layers. Deformability must also be mentioned, which is especially high in "warm" new snow layers. Sharp-grained snow and depth hoar on the other hand display only slight deformability.

The technically correct measurement of snow strength is the business of specialists and even the latter content themselves as a rule with determining a substitute value, ram resistance, which at least gives qualitative information regarding the strength distribution in the interior of the snow cover.

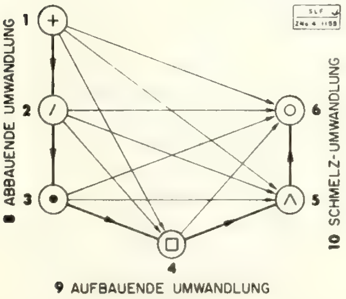
The structure of the snow cover looks quite different from winter to winter and this, as has been shown, also results in a variable long-term basic disposition to avalanche formation.

Figure 2 displays snow profile developments during two winters. That of 1965/66 produced up to the end of January a strong snow cover, while that of 1969/70 on the other hand produced a weak foundation.

3. Avalanche Formation

Strength and deformability of the snow are, next to density or weight per unit volume, the snow properties which are decisive for avalanche formation. In addition, the external friction comes into play after a fracture has taken place. Since each fracture represents the outcome of a contest between stress and strength with strength being the loser, there should first be a discussion of the stress conditions in the snow cover. Actually, they are very complex and scarcely determinable quantitatively. Hence, only a very simplified and basic account can be given.

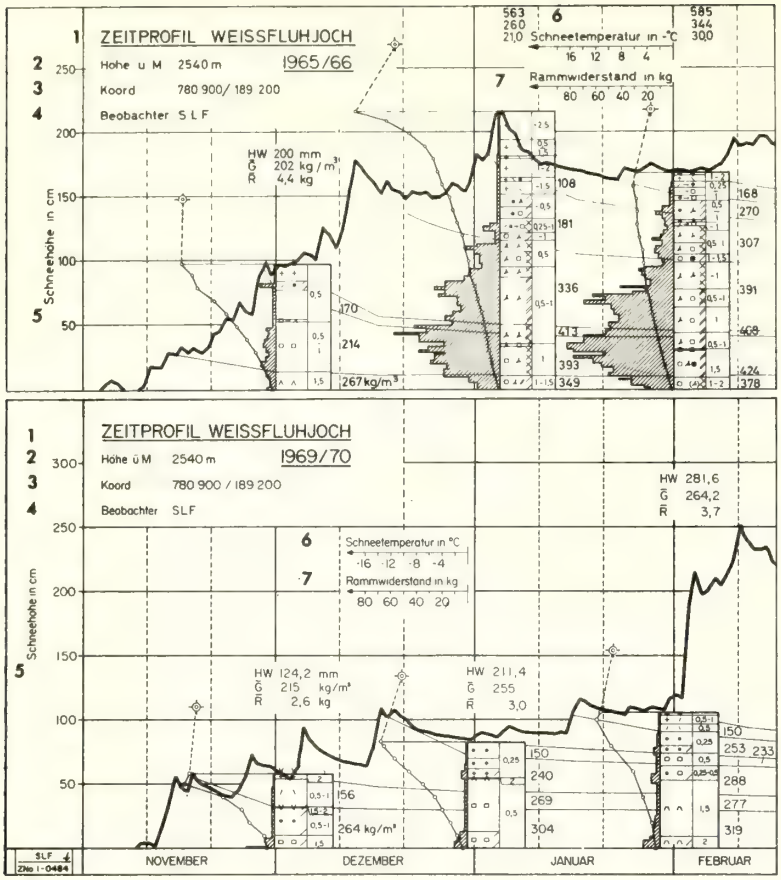
In a horizontal snow cover, there prevails a state of stress which is similar to that in a fluid except for the horizontal lateral pressure. In the case of the fluid, this



Key:

1. New snow (crystals in their original form)
2. Felty snow (crystals partially decomposed)
3. Round-grained snow (without melting)
4. Edged-grained snow (predominantly full forms)
5. Depth hoar (cup or partial forms)
6. Round-grained melting forms (grain growth during freezing)
7. Arrows: possible paths of metamorphism
8. Equi-temperature metamorphism (ET metamorphism)
9. Temperature-gradient metamorphism (TG metamorphism)
10. Melt-freeze metamorphism.

Figure 1. Diagram of snow metamorphism with symbols for the various forms.



Key to Figure 2:

1. Time-profile Weissfluhjoch
2. Elevation above sea level
3. Coordinates
4. Observer
5. Snow depth in cm
6. Snow temperature in °C
7. Ram resistance in kg

Figure 2. Various types of snow cover development (time-profiles Weissfluhjoch, November to February 1965/66 above and 1969/70 below). Heavy curve: snow depth (daily value). Referred to the profile at month's end: heavy curves: negative snow temperature (abscissa); shaded block curves: ram resistance; block diagrams: layer limits. Grain forms and hardness, grain sizes in mm. Numbers on right: snow densities in kg/m³. Numbers above monthly profiles: HW -- total water value; G̅ -- mean density; R̅ -- mean ram resistance. For interpretation see the text.

[pressure] is equal to the hydraulic head [Ueberlagerungsdruck = "pressure of the overburden"]; in snow it is only a fraction of this (about 0.1-0.3). This so-called "nivostatic" pressure is also encountered in an inclined snow cover but changed in magnitude and direction. At the surface it is zero and, in general, increases as one goes downward. If the snow cover is uniformly inclined and everywhere similarly constituted, then all points at the same distance from the surface are in the same state of stress and there exist, apart from the nivostatic pressure, no compressive or tensile stresses parallel to the slope; on the other hand, the snow is subjected to an increasing shear stress as one progresses from the surface to the ground. Thus, the ground everywhere supports the immediately superimposed snow weight in the form of normal pressure and shear stress. Under the prevailing stresses, the snow suffers a continuous deformation which consists of a volume reduction and a shear deformation. The latter is recognizable as a slow creep motion parallel to the slope which ranges from fractions of a mm to several cm per day, depending upon the nature of the snow, slope inclination, and temperature gradient. In pure creep motion, the snow adheres fixedly to the ground, either because it is frozen or prevented by the ground roughness from undergoing a sliding motion. If, on the other hand, the ground is unfrozen and smooth, then there is superimposed upon the creep a gliding motion.

The slope-parallel weight component of the snow cover is then transmitted to the ground as sliding friction.

If now the creep motion and gliding motion are locally modified by differences in the slope inclination, in the snow characteristics or by direct obstructions, there arise marked dislocations of stress. At all retarding and damming obstacles there arise pressure forces which are also effective in the snow as far as the zone of obstruction extends. Conversely, tensile forces form in the snow below anchoring zones and flat regions. Under these conditions, the snow cover is no longer supported at every location by its underlying material. This support continues to exist only in the zones designated "neutral" (Figure 3).

This stress picture which has been sketched here in general terms and the previously described material strength conditions in the snow characterize the formation of slab avalanches (Figure 4). There, where the stress first attains the strength limit, the primary fracture takes place. What actually occurs is a tensile crack perpendicular to the snow cover in the zone of tension or a shear crack parallel to the slope in a weak layer, with a tendency to start in the neutral zone. The lateral shearing crack and compression fracture at the foot of a slope are not likely to be primary fractures. At first glance, the question of the location of the primary fracture appears irrelevant. But when it is a question of avoiding the fracture (touristic) or of hindering it (avalanche control personnel), it is important to know that the origin of an avalanche is just as likely to be in the middle of a slope as in its upper parts.

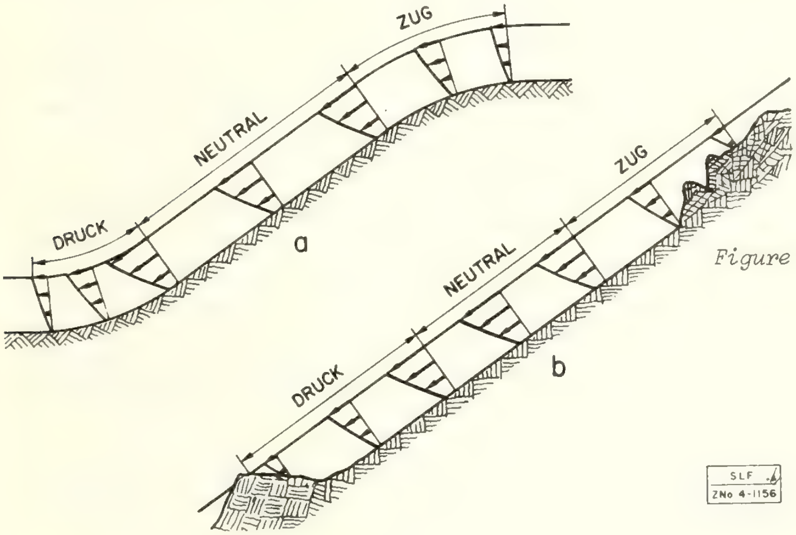
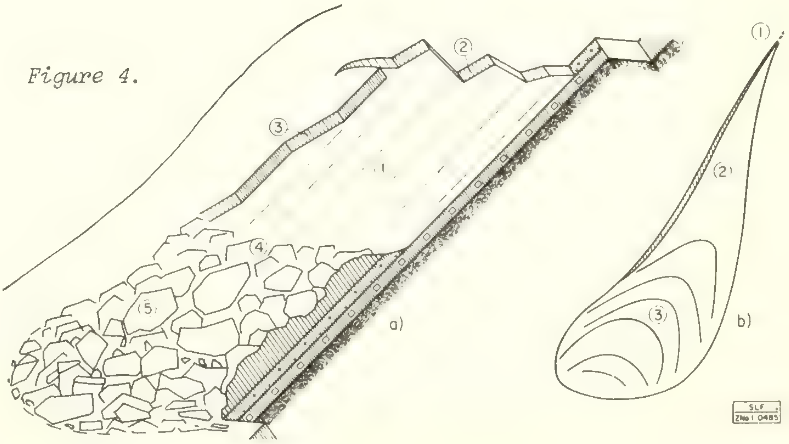


Figure 3. Slope-parallel creep and gliding velocities and stress zones in the snow cover. a) With slope variations; b) With tensile anchoring and compressive support.

Figure 4.



Types of avalanche fracture.
a) Slab avalanche (upper avalanche) with logitudinal section:
1 -- sliding surface (primary or secondary shear crack); loose layer in the snow cover; 2 -- fracture face [crown face] (primary or secondary tensile crack);
3 -- lateral shear crack (secondary); 4 -- compression fracture (secondary) and stauchwall for sliding snow; 5 -- deposition (possibly continued below);
b) Loose-snow avalanche:
1 -- starting point (starting impulse possibly coming from above);
2 -- sliding surface; 3 -- deposition (possibly continued below).

A primary shear crack which results in an avalanche, propagates surface-wise toward all sides since with resolution of the stress in the fracture surface neighboring regions become all the more heavily loaded. In this way, the fracture also overcomes zones of higher stability. The visible tensile crack occurs in the form of a secondary fracture especially in a location where the shear crack penetrates into a zone of tension. A more precise examination of the shear crack in a markedly metamorphosed loose layer, e.g., in a layer of depth hoar or in a snow-covered surface-hoar layer, shows that such layers are also susceptible to compression which is perpendicular to the slope so that even on horizontal surfaces under additional load (new snow, skiers), structural collapse has been observed which is accompanied by a characteristic "boom" noise and a quick settling. With this collapse there is also a deterioration of shear strength. On the slope, it is usually impossible to decide whether pure shear was at work or whether there was a participating compression collapse. Here, too, a knowledge of the possible compression collapse would be of practical significance. Such a structural collapse can propagate from flat terrain toward a slope and trigger avalanches -- as has been confirmed by reliable observations.

The primary tensile crack is not, as is usually assumed, fully accounted for in this description. It will often be located in hard-pressed, brittle surface layers at the beginning of an avalanche. In this case, too, propagation takes place by stress transfer to neighboring regions with assistance being given -- presumably more than in the case of the primary shear crack -- by the elastic shock arising from the fracture.

The primary fracture does not always result in a sliding of the snow slab, either because the primary crack is halted in snow layers of higher stability or the friction in the fractured shear surface is too high to permit motion. Assuming dry friction, the friction coefficient of snow against snow lies in the range 0.2-0.6 so that slope inclinations of about 12°-30° are needed to produce motion.

In addition to the slab fracture type, another type is observed which cannot be interpreted by means of the above-described mechanism: snow motion develops from a point at the surface and acquires breadth and depth with the snow moving from the outset in the form of individual crystals or clumps. The loose-snow avalanche (Figure 4b) originates, as the name indicates, with snow of slight cohesion. A small impulse suffices to set a clump of snow in motion when it does not start spontaneously. It collides with particles lying further down the slope and these in turn attach themselves to the motion and propagate it. The potential energy released by the sliding serves to loosen further particles and overcome friction; the excess energy goes into energy of motion. Since the lateral propagation of the motion is small, the front becomes ever more violent. On the whole, a loose-snow avalanche develops more slowly than the slab avalanche, and since in its upper course it usually includes only a thin layer, there it is relatively harmless. Also of essential importance is the fact that it arises only on very steep slopes (over about 40°) and only beneath some disturbing agency (e.g., skiers) and hence cannot be triggered from below.

After explaining the fracture mechanism, it is necessary to consider the conditions which make this mechanism possible.

With the loose-snow avalanche there arises the question of the circumstances under which snow becomes labile. In the first hours after deposit, loose new snow possesses a toothed structure which endows it with minimal strength. With the immediate onset of ET metamorphism, the dendritic structure of the crystals is partially lost before a true granular binding can build up. In this state, the snow is ripe for the production of dry loose-snow avalanches. If new snow is exposed to strong solar irradiation or heating, the ET metamorphism can be immediately converted into a superficial wetting and the result is the wet loose-snow avalanche. But coarse-grained old snow is also prone to produce loose-snow avalanches whenever the first thorough wetting in spring decomposes the granular binding before true glacial ice is formed.

Corresponding to the formation mechanism which has been described, the precondition for a slab avalanche lies either in an increase in stress or in a decrease in strength at the decisive locus of minimal stability. But it is possible for both processes to lead simultaneously to fracture. If at first one disregards external disturbances applied to the snow cover either by human or other sudden agencies, snowfall is seen to be the most important source of loading for an already existing snow cover. Since the new snow itself accumulates with relatively slight strength of its own, the stability in the interior of a layer of new snow is often less than in the underlying old snow and during an intense snowfall, under certain circumstances, the strengthening of the new snow can fail to keep pace with the increase in loading. Naturally, a minimal slope inclination and a minimal increase in snow is required to produce fracture. The more heavily it snows, the lower lies this critical slope inclination and the smaller is the critical snow accumulation.

Under otherwise equal conditions, a new snow fracture occurs first in steeper terrain and only later in flatter zones. At the highest snowfall intensities (e.g., snow accumulation of 5-10 cm/hr) the stability on slopes can become critical at an inclination as low as about 25°. Here the nature of the new snow and its temperature play an essential role. Low snowfall temperatures (below about -7°[C]) hinder the development of strength and thus promote the formation of avalanches on steep slopes and in addition extend the risk of avalanches to flatter terrain.

New snow stability is quite decisively affected by wind. Two unfavorable effects should be noted: most important is irregular deposit which in lee zones can produce snow accumulations many times the average. This gives rise to peak loadings which can be further enhanced by irregular creep motions. The second effect of the wind is to make the snow brittle. While this does produce an increase in strength, the stress peaks cannot be equilibrated. This last effect is especially significant for tourists.

How does the stability of the old snow cover behave when loaded with new snow? It is then that the old snow surface is for the first time subject to loading. If, as often happens after cold periods of fair weather, it is subjected to TG metamorphism or even covered with surface hoar, its strength usually becomes less than that of the new snow and the slab avalanche will not be long in coming (primary shear crack). Catastrophic large-scale avalanches are less likely under such conditions since the fractures occur at only moderate accumulation of snow.

In addition to the surface first covered by new snow, there are in the depth of the snow cover, depending upon the previous development of the winter, additional old surfaces of the same type and often in the neighborhood of the ground there is still a weak depth hoar layer from the time when the ground was first snow-covered. These layers do possess a certain set and consolidation, but it can be that one of them, because of the higher loading at deep levels, has the least stability and becomes activated as a fracture surface (old snow fracture). Because of the increased magnitude of the snow mass set in motion, such fractures in old snow have an aggravating effect upon pure new snow fractures in catastrophic situations. Depending upon the course of the winter, more or less strong and dense layers lie between the weak layers and these layers have an avalanche retarding effect if they are not limited to the uppermost snow layers.

Temperature has thus far been mentioned as a factor in avalanche formation only in connection with new snow. Its effect is concentrated upon the strength development of the snow and is not always easy to survey. On the one hand, of two snow samples having the same structure but different temperature, the colder one has greater strength than the warmer, but on the other hand, the warmer sample can consolidate better as a result of compaction and thus it overtakes the colder sample in strength. Absorption and emission of radiation as well as variations in the air temperature lead to variable temperature drops in the snow and to the metamorphic processes which have been mentioned and which result, according to circumstances, in a retardation or promotion of strengthening.

When snow temperature reaches 0 and melt water is produced, new effects arise. First, the snow becomes sticky or snowbally and hence somewhat stronger. But with more marked wetting a distinct reduction in strength is observable. The first moistening of the layer adjacent to the ground leads to gliding snow motions or to the fracture of wet ground avalanches. Speaking generally, a marked warming results in a critical increase in avalanche activity which diminishes after a while and in particular, after a cooling off.

The underground conditions have a variety of effects upon avalanche formation. Contrary to a widespread conception, ground roughness does not play a decisive role. Once the ground irregularities have been covered and smoothed out by the action of the wind, the formation of upper avalanches (i.e., the slippage of upper layers) is largely independent of the underground. Nevertheless, upper level avalanches are hindered to the extent that roughness elements (blocks of stone, vegetation) project into the snow cover. In early winter, rough terrain can take up much more snow before the descent of avalanches than in midwinter and late winter. In this sense, the absolute snow depth is also a factor in avalanche risk.

4. Snowfall and Snow Distribution

Thus far, avalanche winters have always been closely related to periods of intense snowfall (1945, 1951, 1954, 1968, 1970). Heat waves have probably led to accumulations of serious ground avalanche occurrences, but not to widespread cases of damage. This is a consequence, among others, of the fact that wet snow avalanches generally display smaller extents and are more inclined to stay in familiar paths than are dry surface-type flow avalanches and powder avalanches.

For the practical man, it is important to know where and with what frequency great snowfalls are to be expected with special emphasis being given to daily values of new snow amounting to 50 cm and more. Catastrophic events must be reckoned with whenever the new snow totals over several successive days (sum of the daily values designated by ΣHN) amount to about 120 cm. At low temperatures (under about -8°) the series is not interrupted by a single intermediate day when there is little new snow. On the other hand, snowfall pauses at high temperatures permit the new snow to consolidate and delay or prevent the development of an avalanche. (Naturally it is the temperatures in the region of initial fracture which are decisive.) When strong winds prevail from a steady direction, the catastrophic quantity can be attained at low new snow totals, in which case the danger is concentrated in zones which are in the lee of the wind. Thus, there is a general risk of avalanches with catastrophic tendency for valley situations as soon as a new snow total of about 100 cm is attained within 3 days. The frequency with which this case arises in various regions of Switzerland is shown by the following summary for some stations over a period of 20 years.

Frequency ΣHN ≧ 100 cm in 3 days (1950-1970)

Zuoz (1,730 m)	Once
Barberine (1,820 m)	Four times
Davos-Platz (1,560 m)	Six times
Andermatt (1,440 m)	Seven times
Bedretto (1,400 m)	Fourteen times
Grindelwald-Bort (1,570 m)	Seventeen times

Thus, there exist substantial regional differences, with the alpine border zones being most frequently affected. The extent to which terrain conditions and settlement conditions are involved in catastrophic events is shown by the example of Grindelwald where in the period mentioned, no avalanche catastrophes occurred. (For further references to new snow data, see Th. Zingg in the SLF Winter Report 1961/62, No 26.) A compilation of local snow and weather data from the avalanche periods mentioned at the outset should confirm these generalizing statements.

Weather and Snow Conditions for the Avalanche Catastrophes 1945, 1951, 1954, 1968, 1970

The notation is:		
	HN	Daily new snow (morning value), cm
	$\sum_i$HN	Totaled daily values during i days, cm, up to the time of the avalanche
	HS	Total snow depth on the ground, cm
	T	Air temperature, °C
	W	Wind force (mean value), m/s

Andermatt, Kirchberg Avalanche, 8 March 1945 (afternoon)

Datum	HN	Σ HN 3	Σ HN 5	HS	T	W
5. 3.	30			(170)		
6. 3.	5					NNW 8—11 (in 2000 m)
7. 3.	40				—(7÷10)	
8. 3.	55	~115*	~145*	300		
9. 3.	40					

* Includes addition to morning value of 8 March: 15 cm.

St. Antoenien, Meierhof Avalanche, 20 January 1951 (2130 hours)

Datum	HN	Σ HN 3	Σ HN 5	HS	T	W
16. 1.	25			125	—5	
17. 1.	15			124	—7	
18. 1.	12			120	0	SW 4,5
19. 1.	44			158	—5,5	SW 2,5
20. 1.	65	~157*	~197*	200	—1,5	W 4,5
21. 1.	73			240	—0,5	SW 1

* Includes addition to morning value of 20 January: 36 cm. Additional avalanches: at night 18-19 January; 20 January, 0300 hours; 21 January, 2130 hours.

Airolo, Vallascia Avalanche, 12 February 1951 (0045 hours)
(Snow measurement by Bedretto)

Datum	HN	Σ HN 3	Σ HN 5	HS	T	W[4]
4. 2.	12			163	—5	
5. 2.[1]	52			210	—4	
6. 2.	57			253	—2	
7. 2.	25	(134)	(139)	265	—6	
8. 2.	0			250	—5	
9. 2.[2]	1			230	—2	
10. 2.	14			244	—1	
11. 2.[3]	55			285	—1	
12.2.	125	~152*	(~153*)	370	0	
13.2.	46			368	—1	

* Reduced daily value of 12 February: 83 cm.
1 Evacuation of parts of Airolo.
2 Return of the evacuees.
3 Repeated partial evacuation.
4 No reliable wind observation by Bedretto. In the heights generally SE wind 5-10 m/s

St. Antoenien, Aschueel Avalanche, 12 January 1954 (0030 hours)

Datum	HN	Σ HN 3	Σ HN 5	HS	T	W
9. 1.	—			27	—22	
10. 1.	16			42	—13	
11. 1.	50			91	—12	SW 7
12. 1.	85	~129*	(~131*)	171	—12	(Höhe WNW 15) **
13. 1.	4			145	—11	

* Reduced daily value of 12 January: 63 cm.
Additional avalanches on 11 January.
** Data from the Weissfluhjoch. (High level WNW 15)

Davos, Dorftaeli Avalanche, 26 January 1968 (2240 hours)

Datum	HN	Σ HN 3	Σ HN 5	HS	T	W
						**
23. 1.	—			97	—6	NW 5—8
24. 1.	—			94	—7	NNW 11—23
25. 1.	18			106	—8	NNW 17—20
26. 1.	42	~107*	(~107)*	138	—4	NNW 21—32
27. 1.	79			185	—3	NNW 16—28
28. 1.	15			166	—5	NSW 3—6

* Includes addition to morning value of 26 January: 47 cm.
** Wind values from the Weissfluhjoch (high fracture region).
Additional avalanches: among others, 27 January, 0030, 0400, 0600 hours.

Reckingen, Baechital Avalanche, 24 February 1970 (0550 hours)
(Observations by Muenster)

Datum	HN	Σ HN 3	Σ HN 5	HS	T	W
19. 2.	5*			139	−6	SW 3
20. 2.	11			144	−2	NW 3
21. 2.	22			154	−5	O
22. 2.	48			186	0	O
23. 2.	21			194	+1	SW 16
24. 2.	16	85	118	196	−4	O

* From the 3d to the 18th of February, the new snow total amounted to as much as 126 cm.

Comment: In the Andermatt (1945) avalanche, in view of the low temperature, presumably the new snow total of 5 days was a factor, although the 3-day value almost attained the assumed catastrophic mass. In St. Antoenien (1951), the relatively high temperatures had a somewhat delaying effect and allowed the catastrophic mass to exceed 150 cm in the last 3 days alone. The Airolo (1951) avalanche would have been almost ripe on 7 February. With the 2-day snowfall interruption at a relatively high temperature the situation recovered and an additional equally large load of new snow was required to generate the avalanche.

In St. Antoenien (1954), the effective agent was exclusively the snow accumulation of 3 days, fallen at low temperature and moderate wind.

In the Davos (1968) case, one is struck by the relatively low new snow total (107 cm) at the onset of the extraordinary avalanche activity. Here, for an explanation, one can appeal to the sharply blowing winds coming always from the same direction. The Reckingen (1970) avalanche probably includes all the February snowfalls, which represent an unusual sequence.

5. Avalanche Dynamics

Depending upon the nature of the snow and the terrain conditions, broken masses of snow move in quite varied ways. In the case of slab avalanches, there develops a translatory motion in clods which sooner or later decompose into a lumpy, powdery, or (in the case of wet-snow avalanches) even pasty mass. The sliding motion is triggered by a flow having a velocity which increases from the ground to the surface. The motion soon becomes turbulent, and if the snow is dry and fine-grained or downy, at a velocity of about 10 m/s snow dust begins to separate at the surface. As long as the mass follows the ground substantially, one speaks of a flowing avalanche and after most of the snow component has been carried up turbulently into the air, one speaks of a powder avalanche. Often both forms are represented side by side as a flowing avalanche component and a powder avalanche component.

A jump over a terrain edge can almost cause the flowing component to vanish and result in a practically pure powder avalanche.

The loose-snow avalanche often develops at first a peculiar form of motion in which the displaced front continually presents new snow in front of it. In this case, the position of the front propagates more rapidly than the snow particles themselves. But later the front will shoot away over the resting snow cover and the latter will only then resume involvement in the motion. It is then scarcely possible to distinguish between the slab avalanche and the loose-snow avalanche.

With regard to the size of the velocities attained by smaller and average avalanches, we possess some information from measurements, observations, and photography. Of catastrophic large-scale avalanches, there exist in general no measurements and eyewitness reports are often very divergent. Well known are the observations by M. Oechslin of some avalanches (1938) in UR which in part give almost unimaginably high values (up to over 380 km/hr).

In all observations and measurements, it is frontal velocities which are involved while it must be assumed that in the interior of a mixed flowing and powder avalanche (apart from the cited case of the loose-snow avalanche), there prevails a somewhat higher core velocity. Since the friction forces (turbulent and viscous friction) themselves depend upon the velocity, for a given descending mass a certain mean terminal velocity is attained. This will generally lie substantially below the velocity of the frictionless case over a drop distance h ($v = [2gh]^{1/2}$). Because of their small friction component, powerful powder avalanches can attain high terminal velocities.

Realistic mean velocities of large avalanches may be expected, in a descent path having 38-40° inclination, to lie roughly in the following ranges:

Wet-flowing avalanches	10-30 m/s
Dry-flowing avalanches	20-40 m/s
Powder avalanches	30-70 m/s

The most important phenomenon accompanying moving masses of snow is the pressure on opposing obstructions. It is proportional to the density and to the square of the velocity. With full frontal obstruction at a wall, it amounts to

$$p = \frac{\gamma}{g} v^2 \ (\mathrm{kp/m^2})$$

where γ equals specific weight ($\mathrm{kp/m^3}$)[2], g equals gravitational acceleration 9.81 $\mathrm{m/s^2}$, v equals velocity (m/s). In the case of flow around obstacles, form factors must be employed. The specific weight of a moving avalanche is not precisely known. Reasonable estimates are:

Wet-flowing avalanches	300-400 $\mathrm{kp/m^3}$
Dry-flowing avalanches	50-300 $\mathrm{kp/m^3}$
Powder avalanches	2- 15 $\mathrm{kp/m^3}$

The intermediate range from 15 to 50 $\mathrm{kp/m^3}$ is encountered in the transition zone of mixed flowing and powder avalanches.

As early as 1936, pressures in heavy flowing avalanches of 50-60 $\mathrm{t/m^2}$ have been measured (Goff and Otten, USSR) and these have subsequently been confirmed several times in Switzerland. Powder avalanches, despite their bad reputation and their high velocity, are less violent. Pressure values above 10 $\mathrm{t/m^2}$ probably occur rarely. Nevertheless, normal buildings and forests cannot possibly withstand such forces, especially as these usually attack several meters (5-20) above ground.

There is often ascribed to powder avalanches an air pressure effect speeding ahead of the actual avalanche front with a force of the greatest destructiveness. Undoubtedly an air cushion arises immediately in front of the visible avalanche front, and the compressed air must escape from there forward and upward at avalanche velocity. But since it is essentially lighter than the dust cloud, the pressure effect of this advance wind will be slighter than that of the snow dust -- which is not to say that it is incapable of destruction.

References to further dynamic phenomena, particularly frictional conditions, flow heights and ranges of action may be found in the paper by B. Salm ("Five Principles of Avalanche Control").

6. Classification of Avalanches

Observations relating to avalanches may be subdivided into observations relating to the external appearance of the avalanches and those which have to do with the conditions of formation. Hence, one distinguishes a classification of appearance forms (morphological classification) and a classification according to the conditions of formation (genetic classification). International efforts are underway to create uniform classification procedures, with the schemes introduced in Switzerland as early as 1955 serving as guides.

A true genetic classification which unambiguously assigns complex conditions of formation to observed or expected avalanches does not yet exist, and will perhaps never be set up in this form. On the other hand, with regard to avalanche formation, it is possible to isolate decisive factors and to present a clear overall picture of their significance. For the present, it must be left to the person making a judgment of a developing avalanche situation or of an avalanche event to apply the correct weights to the interplay of genetic factors. Automated computer procedures are still in their initial stages.

The terrain occupies a special position in classification. It constitutes a precondition which is locally fixed and constant in time and displays both morphological and genetic aspects.

For the features of interest, the observed (or to be expected) characteristics are used alternately in suitable combination. Occasionally, two characteristics enter as components. Example: dry, soft-slab avalanche, starting as upper avalanche with old snow fracture, descending as trough avalanche with predominant powder component.

Complete description of an avalanche requires supplementation by means of measurable (quantitative) quantities such as fracture elevation, breadth, volume, velocity, etc., which require no classification system.

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[2] kp = kilopond force: 9.806 kp = 1 newton. The magnitude of kp measurements is the same as for kilograms.

6.1 Morphological Classification (According to Appearance)

Feature	Characteristics	
Upper fracture boundary	Linear Slab avalanche[3]	Point Loose-snow avalanche
Position of the sliding surface	Within the snow cover Upper avalanche	On the ground Ground avalanche
	New snow fracture Old snow fracture	
Fluid water in the avalanching snow	Lacking Dry-snow avalanche	Present Wet-snow avalanche
Form of the path (transverse profile)	Flat Flat [unconfined] avalanche	Trough-shaped Trough [channelized] avalanche
Form of the motion	As dust cloud Powder avalanche	As a flowing mass Flowing avalanche

[3] May be further divided into soft and hard slab.

6.2 Summary of Genetic Avalanche Factors (Formation Conditions) (Survey)

Condition	Effect Upon Avalanche Formation
Recent weather (3-5 days)	
New snowfall	Progressive increase in avalanche tendency. Most important factor!
Growth and intensity	Mainly upper avalanches (see special table 6.2.1)
Wind	Local slab formation
Velocity, duration, and direction	Amplified on leeward slopes (snow drifts) with and without snowfall. Wind $\geqq$ 4 m/s.
Air temperature and radiation balance (Effect through snow temperature)	With increasing snow temperature decreasing strength and increasing deformability. Effect complex. Often temporarily increased avalanche activity (especially with wetting). Low temperature preserves the existing situation. Secondary temperature effect: snow metamorphisis.
Old snow conditions	
Total snow depth	In general a subordinate factor. With increasing snow depth reduced avalanche retarding effect from ground roughness, sometimes increased avalanche volume in the case of an old snow fracture.
Stratification of the old snow cover (Record of the development of the winter)	Strength development of the lower and intermediate layers (TG metamorphism, surface hoar) decisive for old snow fracture (sometimes avalanche risk without new snowfall).
Triggering conditions	
Natural formation	Spontaneous avalanche (without sudden disturbance). Natural trigger (with sudden disturbance).
Trigger by man	Accidental trigger (unintentional). Artificial trigger (intentional).

6.2.1 New Snow Depth and Avalanche Formation

(Guide values, valid for wind up to about 4 m/s, temperature -2° to -10°

New Snow Total in 3 days (cm)	Avalanche Formation
Up to 10	Rare, very local snow movements (mostly loose-snow avalanches).
10 - 30	Occasional local slab formations. Frequent loose-snow avalanches.
30 - 50	Frequent, local slab avalanches, mostly on steeper slopes (>35°).
50 - 80	Widespread slab avalanches also on more gentle slopes (>25-30°). General risk above the tree line. Individual larger avalanches down to the valley floor, mostly in familiar paths.
80 - 120	Frequent, large avalanches down to the valley floor, occasionally also outside familiar paths.
>120	Extraordinary conditions. Rare and hitherto unknown great avalanches possible.

At temperatures below -10°, the summation period should in some cases be extended to 5 or more days. At wind above 4 m/s, the evaluation class for leeward exposures should be raised by one to two levels depending upon velocity and duration.

6.3 Classification of Terrain Conditions

Terrain	Effect Upon Avalanche Formation
Slope	
0° - 11°	Expansion and deposition stretches of dry flowing avalanches.
11° - 20°	Dry, flowing avalanches in motion run through.
20° - 30°	Rare formation of slab avalanches (tendency increasing progressively with slope).
30° - 50°	Normal range for slab avalanches.
40° - 60°	Normal range for loose-snow avalanches.
> 60°	Frequent continuous sliding of loose snow.
Exposure (orientation)	
With regard to the sun	Variable effect of irradiation. Southern exposure: Temporarily increased avalanche formation (in some cases wet-snow avalanches). Increased consolidation. Northern exposure: In general, bad lower layers, depth hoar, surface hoar (see table 6.2, air temperature and radiation balance).
With regard to wind	Displacement of snow from windward slopes to leeward slopes (slopes protected from the wind); see table 6.2, wind.

General shape

Flat surfaces, gentle changes in slope	Tensile and compressive stress zones, fracture regions.
Corrugations, gullies	Boundary of starting zones, avalanche paths.
Steps, hollows	Jump intervals (powder avalanches!), trap intervals; see table 6.1, morphological classification.

Roughness

Smooth flat areas, grass	Gliding snow, ground avalanches possible.
Rough gravel	Adherence of the ground layer (depending upon roughness), upper avalanches possible.
Shrub vegetation	Avalanche-retarding, as long as not snow-covered.
Forest	Avalanche-retarding if dense (limited retarding and trapping capacity).

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III. AVALANCHE PROTECTIVE MEASURES (Hans Oppliger, Glarus)

1. Introduction

In his book The Avalanches of the Swiss Alps, Chief Forest Inspector J. Coaz wrote in the year 1881: "In the first decades of our century, the Alps of Switzerland, and in particular the actual high mountains themselves, were seldom visited, very scantily investigated, and hence still rather unknown -- almost a terra incognita rising directly out of the midst of countries which are among the most heavily populated and the most cultivated on earth. Since then, the situation has become quite different, and nowadays every summer there takes place a small migration toward the Swiss Alps and many visitors penetrate into their most remote regions in pursuit of the most varied intentions."

In those days, Coaz was experiencing the beginning of the conquest of our Alps. He could have no idea of the future extent of this development, which today has still not been concluded. Actuality has surpassed even the boldest expectations. From what were formerly small mountain hamlets sandwiched between avalanche trails, there have now arisen sophisticated summer and winter holiday resorts and more and more people live part of the time today in the mountains. The enlargement of the mountain hamlets and the associated expansion of transportation routes in and through the mountains confront the responsible authorities of entire regions with almost insoluble problems. Special difficulties arise during the winter when in many parts of our alpine valleys avalanches descend which often advance down to the floors of the valleys. This can directly endanger settlements, transportation routes, and transportation facilities. The population of our mountain regions knows the risk associated with avalanches; in fact, they must live with avalanches. As a consequence of the marked expansion of travel from abroad, but especially through the popularization of winter sports and of winter tourism, more and more inhabitants of flatland are being confronted with avalanche endangerment, either as temporary guests of winter resorts, as travelers on mountain roads, or as tourists who have left the beaten path of safe transportation routes. An understanding of the danger of avalanches and a knowledge of possible protective measures has become an absolute necessity of life in the mountains. The entire public must concern itself with the resulting technical problems and financial costs; for in many mountain valleys an effective avalanche protection is an essential condition of the continued existence of numerous communities.

All avalanche-protective measures pursue the goal of protecting men and property from damage: men as inhabitants of communities exposed to avalanche risk or of individual farms and as tourists, or as users of public communication routes and transportation facilities (paths, roads, railways, cablecars, ski lifts), in open work places (building sites, forests), or in closed working places (workshops, factories, hotels); the property consisting of buildings, furniture, cattle, transportation facilities, technical facilities, forests, and fields. Basically, a distinction can be made between short-term and long-term protective measures. Both types have their advantages and disadvantages. In the individual case, they must be weighed against one another while taking into account engineering possibilities, the protection task, urgency, the time required, costs, and legal principles. In planning them, it is also necessary to evaluate the ratio between financial cost and the importance of the object to be protected.

2. Short-Term Avalanche Protective Measures

Short-term measures for the prevention of avalanche accidents relate to individual avalanche situations in which the special episodes of danger must be evaluated from case to case. Often it is a matter of personal measures which have been left to the judgment of an individual, such as selection of routes, the decision to dispense with planned undertakings, observance of general and local avalanche warnings or evaluation of local snow, weather, and terrain conditions. As collective protective measures, short-term protective measures also include all precautions taken by avalanche services, ski-slope services, or rescue services. These measures are avalanche warning; closure of endangered routes, transportation services, and regions; evacuation of endangered communities or parts of communities; artificial triggering of avalanches and readiness of rescue services. Short-term protective measures should also be taken to avert an acute avalanche danger in order thereby to bridge the gap produced by the time-consuming planning and design phase of long-term measures.

2.1 Cautionary and Protective Measures in Patrolling Avalanche Endangered Regions

It should be possible to assume that all visitors to and inhabitants of mountain regions will observe the most elementary measures of caution. Unfortunately, it is precisely in the case of ski tourists that the most surprising carelessness with regard to avalanche danger may be seen. Many a major avalanche accident claiming many lives might have been avoided if reasonable safety precautions had been observed.

Probably the most important protective measure is clarification with regard to the urgency of an entrance into avalanche endangered zones. In a doubtful case, one should dispense with carrying out an undertaking which is not absolutely necessary. Before beginning an unavoidable patrol, all risk factors must be thoroughly investigated. Serviceable in this connection are: the general avalanche bulletin, local avalanche warnings, snow reports, and information released by local avalanche or ski-slope services. The greatest care should be accorded the selection of routes, by evaluating topography, snow quantity, type of snow, snow distribution, and weather. In gathering this information, connoisseurs of local conditions should also be consulted. In particular, unconditional heed should be given to the warnings, instructions, and closures issued by the local avalanche services. Before any dangerous undertaking, the responsible leader must be aware that his project will endanger the lives of not only himself and those accompanying him, but also those of any members of the rescue service which may possibly be required.

2.2 Avalanche Service

The avalanche service is organized by the political authorities of a community or of an entire region. Its range of tasks includes, as a rule, keeping watch on all avalanche paths existing within a community which represent a source of danger for a settlement, for individual objects, for transportation facilities, or for tourists. The existence of an avalanche service does not make the personal protective measures of individuals superfluous. The population of endangered regions must take basic cautionary measures in every case and without being specially called upon. This applies especially to the patrolling of zones which manifest certain degrees of risk even when there is only slight general avalanche danger but which are not covered by the avalanche service at all or only in certain cases.

The avalanche service fulfills two main functions. On the one hand, it takes all measures for prevention of avalanche accidents, and on the other hand, it organizes the measures of assistance which are necessary after the occurrence of an avalanche accident. From this double task there arises a division into various services to which specific tasks are assigned. The lookout service begins its activity when there are intense snowfalls. A continuous situation evaluation is carried out with the aid of the weather reports of the Swiss meteorological central institute and its internal announcements together with the avalanche bulletins of the Federal Institute for Snow and Avalanche Research (EISLF) and in cooperation with the snow and avalanche specialists of this institute. The evaluation of observations and announcements of specialists serves as the basis for recommendations to the avalanche commission or to the community council which then, through the warning and alarm service, institutes the alarm measures which it considers necessary. The levels of warning and alarm to be employed must be precisely described and established in an official regulation. The warning and alarm service sees that all levels of avalanche alarm are supplied under all circumstances, and immediately to the persons concerned. After the avalanche danger has passed, this service is also responsible for complete withdrawal of the warning. The institution of certain alarm levels gives rise under certain circumstances to evacuations and closing of roads. The evacuation service is responsible for the execution of evacuation orders. In preparation for the smooth execution of evacuation procedures which are not always simple, actual evacuation plans are set up in which there are established the measures necessary for all levels of alarm. This includes precise lists of all persons to be evacuated and the emergency accommodations assigned to them. The closure and surveillance service provides for maintaining the road and traffic closures which have been decreed, provides for the surveillance of evacuated localities, and in the event of avalanche accidents, provides for closing off and surveillance of accident sites. Under certain conditions, the artificial triggering of avalaches is carried out by the avalanche service. The avalanche shooting service is concerned with these problems (compare section 2.3).

Upon the occurrence of an avalanche accident, the rescue service is concerned with providing the immediate and properly directed employment of the required rescue facilities and crews. The health service keeps the personnel required for assistance in readiness, while the materiel service makes the required rescue equipment available. The materiel service is also responsible for appropriate storage and maintenance of the existing equipment. A special maintenance and provision service organizes housing and provision for evacuees and in the case of avalanche catastrophes for those who have lost their homes. The necessary accommodations are made ready in cooperation with the evacuation service. The correct functioning and the coordination of the various service branches through the leadership of the avalanche service are guaranteed by a special communications and message service. Communication is carried out by radio, telephone, and message-runners. In avalanche catastrophes, the information service of the mass media is also important. Often the radio is the only still functioning communication device in contact with cut-off homes or settlements. The information service is concerned with the orientation of press, radio, and television, and provides for wireless communication with isolated settlements. The provision of thorough and objective information for all interested parties is very important in avalanche accidents. A mood of panic is often generated by sensational news reports, and this panic can sharply interfere with rescue operations in progress.

The construction of a comprehensive avalanche service is urgently necessary for many communities in our alpine valleys. Proper rescue services exist in many cases (SAC-rescue columns, ski-slope services of the sports areas) and usually can be made available on short notice. What is lacking are the comprehensive avalanche services which are primarily concerned with the prevention of avalanche accidents. These services are of the greatest significance for very many mountain communities and tourist regions.

2.3 Artificial Triggering of Avalanches

The artificial triggering of avalanches is a further measure for the prevention of avalanche accidents. It is employed principally to protect tourist regions and transportation routes.

The most direct, cheapest method of artificial avalanche triggering, but not without danger and limited in its effect, is the technique of stepping or jumping on the snow to release avalanches. In an emergency, this method can be practiced in difficult situations by experienced skiers. True preventive avalanche triggering consists of blasting loose or shooting down avalanches by means of hand operated explosives or by means of artillery.

In Switzerland, avalanches were shot down for the first time in the winter of 1934/35 in the Bernese Alps. The division of military engineers at that time carried out experimental firings with the infantry cannon, the 7.5-cm [75-mm] mountain gun, and with the 8.1-cm mine thrower [trench mortar]. Subsequently, the trench mortar also showed itself to be the best firing device for keeping the upper alpine highway open in the winter 1939/40, and in opening up the Klausen Pass in the spring of 1940. Since these first experiments carried out by the army, preventive avalanche triggering has become widespread in the entire alpine region. Today in Switzerland during a normal winter, between 5,000 and 10,000 explosive trials are run for the purpose of triggering avalanches. The most common practice here is the process of hand operated blasting with safety explosives, which is a very good and not very expensive method. Its greatest disadvantage is its small range of only about 30 m.

Today the standard firing device is the 8.1-cm trench mortar. Its relatively great range, up to about 4,000 m horizontally and about 2,200 m vertically (for 500-600-m horizontal distance), guarantees the safety of the operating personnel, and the great explosive force of the shells makes it a reliable weapon in the battle against avalanches. The ammunition fired has instantaneous ignition. When shells having delayed ignition are used, they do not explode until they have penetrated into the snow cover or into the ground. This merely results in a snow crater without any further effect. When trench mortars are fired, because of the possible propagation of the fracture in the snow cover, one must always reckon with the possibility of unintentional large-scale triggerings of avalanches. The trench mortar can also be used from fixed firing positions. By using pretargeted shooting elements, it is possible to shoot without seeing the target. During long-lasting snowfalls which can lead to dangerous avalanche situations, it is thus possible to carry out continuous firing trials.

Recently the rocket tube has also been used as an avalanche weapon. Its great precision gives it very high hit reliability and, because of its low weight, a mobility is attained which makes the rocket tube an interesting and, for certain uses, ideal weapon; this is in spite of its smaller range (up to 1,600 m) in comparison with the trench mortar and despite its substantially higher ammunition costs.

A further possibility for artificially triggering avalanches lies in the use of minefields. In this process, prior to the first snows, explosive charges are placed in the fracture zones of dangerous avalanches in some suitable arrangement so that they can be electrically fired as needed from a safe location. Because of patent laws, this method is very expensive; hence it is little used in practice.

The artificial triggering of avalanches involves extraordinarily great risks. Incorrect handling of the weapons or of the explosives can endanger the operating crew or third parties. The same consequences can also follow from aiming errors in shooting with trench mortars and rocket tubes. Unintentional avalanche descents or large-scale collapse which can lead to extensive damage are not impossible. Hence, the artificial triggering of avalanches is out of the question for inhabited zones and can be employed elsewhere only within the framework of a well organized avalanche service. One must presuppose the existence of the various service branches such as surveillance, closure, evacuation, firing, and rescue service. Only trained personnel should be employed for operating the weapons and army safety specifications also apply to the civilian use of the various weapons.

Members of the firing service must also concern themselves with the tactical aspect of avalanche shooting. Depending upon the conditions prevailing in the particular case, two different procedures must be distinguished. Large-scale avalanches can be prevented by periodic shooting or the protection of a threatened region can be undertaken only after the conclusion of a period of precipitation or storms. Both procedures require precise and careful preparation.

3. Long-Term Avalanche Protection Measures

Long-term protective measures are understood to relate to numerous avalanche situations. In this way, extreme situations can be taken into account and the measures are as a rule carried out or prepared long before emergence of the danger. Such measures are:

a. Recognition and designation of avalanche endangered regions and prevention of the construction of permanent facilities such as highways, railways, high-voltage lines (avalanche cadastral survey);

b. Designation of zones of prohibited construction and limited construction in endangered regions (avalanche zone plan);

c. Resettlement away from endangered zones;

d. Avalanche control by means of operations in the starting zone, track, or runout zone.

3.1 Avalanche Cadastral Survey

All measures for the prevention of avalanche accidents can actually be successful only when the possible avalanche regions are known. The mapping and comprehensive registration of all significant avalanche paths in our Alps is therefore an extraordinarily important basis for the protection of avalanche zones.

The demand for the collection and processing of avalanche statistics or avalanche cadastral surveys is an old one. As early as the year 1872, the forestry inspectorate of the Canton of Graubuenden commissioned its chief foresters, in a circular, to carry out the collection of cantonal avalanche statistics. On 7 January 1878, the federal forest inspectorate invited the cantons of the federal forest district to employ their forest personnel in the collection of data necessary for the construction of avalanche statistics for the entire Swiss Alps. In order that these first Swiss avalanche statistics should attain a certain uniformity, tables were created which permitted the tabulation of a large number of facts for each avalanche. In the avalanche maps published by Coaz, these statistical data have been evaluated. Unfortunately, the collection of Swiss avalanche statistics was not continued and the original collections are also no longer available.

The idea of creating a comprehensive survey of the occurrence of avalanches persisted in our country and was again taken up after the avalanche winter 1950/51. In the "Guidelines of the Federal Department of the Interior With Respect to Afforestation and Control Projects in Avalanche Endangered Regions" dated 17 June 1952, instructions were included calling for the setting up of avalanche cadastral surveys and avalanche zone plans. Then in the year 1955, the EISLF began the collection of data for a new Swiss avalanche survey. By way of example, the Tavetsch, the Loetschen Valley, and the Hasli Valley were worked up in order to get experience in data gathering, methodology, and presentation of the cadastral survey. For personnel reasons, it was not possible for the EISLF to single-handedly take over the data collection for the entire Swiss alpine territory.

In a circular letter dated 1959, the Federal Department of the Interior recommended once again to the forestry offices of the alpine cantons the establishment of avalanche cadastral surveys and of avalanche zone plans based on the surveys. However, in 1962, the conference of cantonal chief foresters maintained the position that the working up of the avalanche cadastral survey was primarily an affair for the federal government. Hence this work would have to be carried out by the EISLF, with the cantonal forest services being obliged to cooperate in the collection of basic data and in the selection of observers. After this new regulation of the cooperation of the EISLF and the cantonal forest services, it has been possible to work up the survey for various regions. Nevertheless, the work has not yet progressed very far, and up until now, it has been possible for the avalanche cadastral survey to cover only about 5 percent of the target area.

The avalanche cadastral survey has three goals:

a. Scientific investigation of the entire avalanche phenomenon,

b. The establishment and followup of comprehensive damage statistics,

c. The determination and mapping of all zones endangered by avalanches.

By means of the scientific evaluation of a very large number of observations for various avalanches of the alpine region, it is possible to determine the relationships between climate, weather, topography, and avalanche formation. For this a uniform cadastral survey must be set up and there must be continuous observation of the mapped avalanche paths. All information is to be reported to the EISLF which, as a collecting and evaluating center, provides for the subsequent scientific processing of the data. Together with the reporting and recording of all cases of damage, the avalanche cadastral survey constitutes a good aid to avalanche research.

Reliable observation, over a fairly long time span, of the avalanche paths listed in the avalanche survey finally permits a comprehensive review of the danger affecting certain zones of our mountain districts. This will have the effect of facilitating the clarification of various questions having to do with access, patrolability, and of structural and tourist zone planning. The avalanche survey thus becomes an important foundation of local and regional planning.

As a rule, the avalanche survey covers an entire region which has been subdivided into various districts (Figure 1). To each district there is assigned an observer who must cooperate right from the start with collection of basic information and later takes over surveillance of the mapped avalanche paths. The cadastral survey consists of three parts:

a. The description of all mapped avalanches with as much data as possible regarding descents and damage,

b. Damage statistics, in which the reports of observers are collected,

c. An avalanche map (scale 1:5,000 to 1:25,000), in which the avalanches are plotted in their greatest known extent.

Uniform forms are available for the description of avalanches and for the various reports.

3.2 Avalanche Zone Plan

Like the avalanche survey, the avalanche zone plan is also a basic part of avalanche protection. It contains all danger zones in the settled and tourist regions of a precinct and should be contained in the precinct construction ordinance as an integral part of it. The endangered regions are drawn in a plan (scale 1:1,000 to 1:10,000) and the safety regulations applying in these regions are described. As a part of the local planning, the zone plan serves the competent authorities in the evaluation of building applications. In endangered regions, it also forms the basis for construction of the alarm organization within the avalanche service.

The designation of avalanche zones can have drastic effects upon the property owner. Hence, in working up the zone plan, all available information must be utilized. The most important documentations are:

a. The avalanche survey,

b. The topographical conditions,

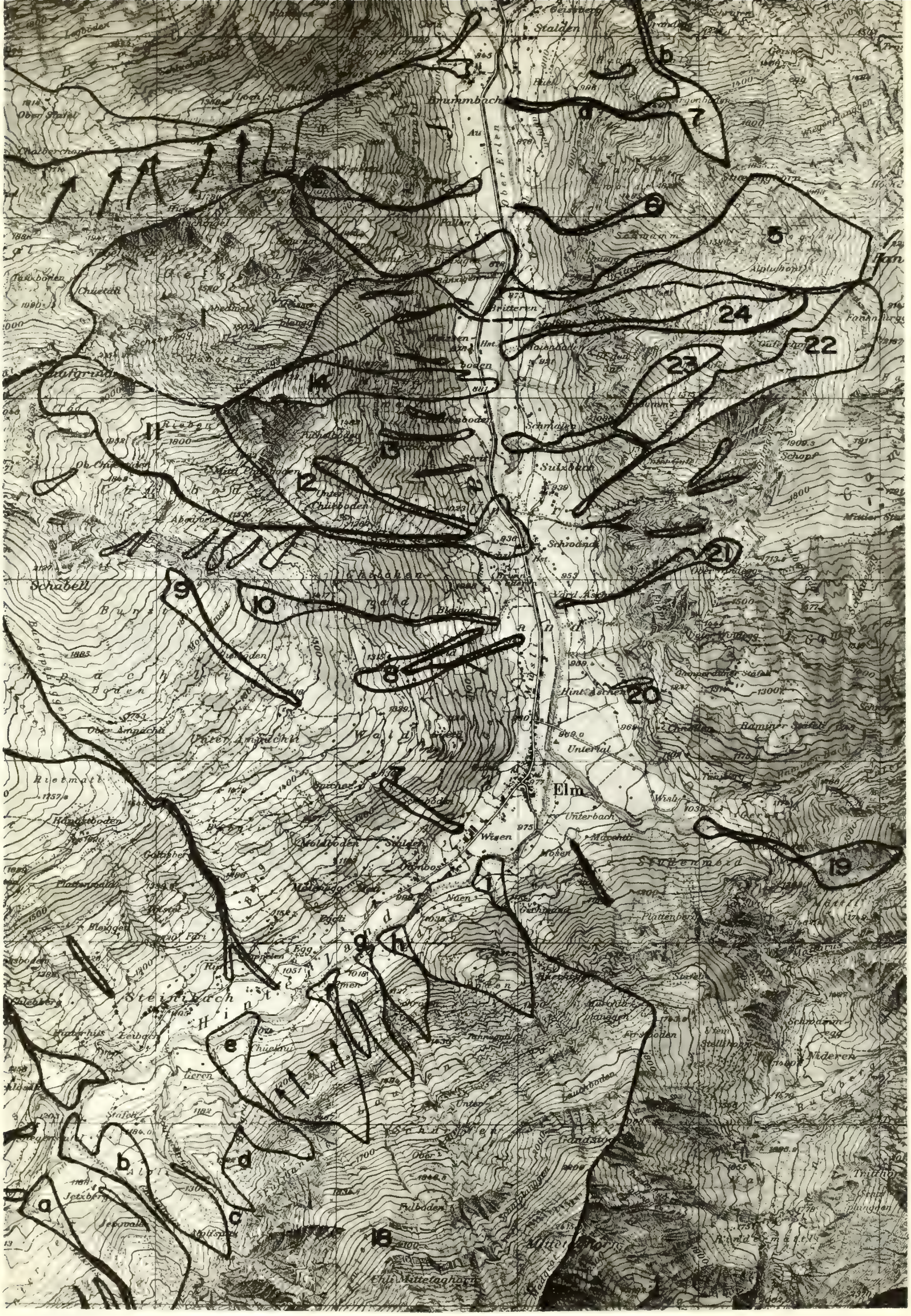
c. Avalanche dynamic calculations (determination of potential avalanches and their forces),

d. The avalanche chronology of the precinct,

e. Avalanche paths in the terrain,

f. Any available danger zone map within the framework of a regional plan,

g. Testimony of competent local authorities.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Unterlal
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Wisli
Moos
Steinibach
Hint
Ober Ampächli
Unter Ampächli
Chüebodenegg
Bleiggen
Ober Stafel
Chalberchopf
Abedweid
Mittler Stafel
Schopf
Alp Falzüber
Chli Mittaghorn

The avalanche survey provides information regarding all avalanche events which have actually occurred and have been recorded. Descents which occurred very far back are not usually contained in it. It is precisely the great and dangerous avalanches with a very long period of recurrence which are missing in the relatively new avalanche surveys. A thorough evaluation of the topography and of the precipitation conditions is therefore important for only by this means can possible avalanche zones be designated on the basis of avalanche dynamic computations. Also the danger zone map, which is substantially based upon the survey and upon avalanche dynamic computations (taking into account terrain and climatic and meteorological conditions) constitutes a valuable aid in working up zone plans. Today unfortunately, these danger zone maps are still largely lacking.

Basically, in the avalanche zone plan those areas are designated which, from the point of view of avalanche risk, cannot be endorsed either conditionally or unconditionally as regions suitable for building. As a rule, there are three different zones. The red zone is characterized by a general building prohibition. Its boundary follows essentially the boundary lines of the largest known avalanches. The drawing of boundaries is supplemented by the avalanche dynamic computations which have been mentioned and by means of which the possible extents of catastrophic avalanches can be determined. No exceptions should be allowed for construction in the red zones unless the building can be used without risk to men and animals (e.g., an alpine hut used only during the summer and provided with correctly dimensioned protective equipment).

The blue zone comes next to the red zone. A certain degree of avalanche danger exists also in these regions. However, the possible avalanche forces can be sustained without damage, as a result of reinforcement or in consequence of special arrangement and improvement of the structures. Hence, dwelling houses are permitted in the blue zone provided certain safety specifications are met. Exceptions are buildings which give rise to a high degree of traffic or to unusually large assemblages of people (churches, schoolhouses, hotels).

In the blue zone, the danger diminishes with increasing distance from the red zone. Hence, it can be subdivided into subzones having different safety specifications (Figure 2). Evacuation duty must be imposed upon the entire blue zone and this requires the organization of an avalanche service. The latter must be sure that in the event of avalanche danger, the inhabitants of the blue zone shall be warned and when necessary evacuated. In this way it will be possible to at least avoid personal damage in the event of an avalanche descent.

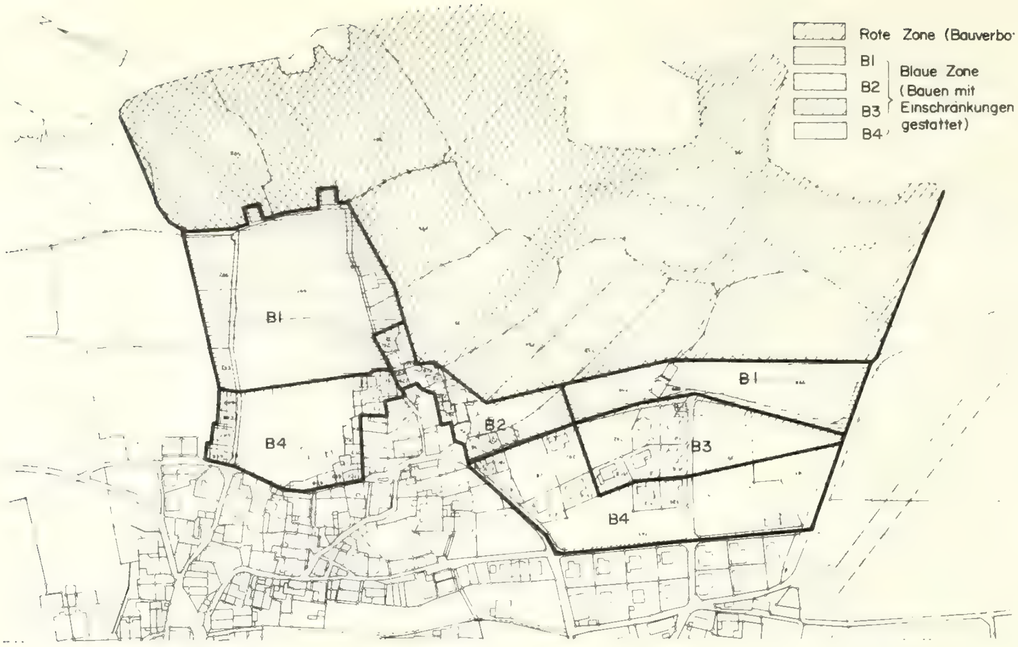
In the white zone, no avalanche danger exists. These regions are left open to settlement. During extreme snow and avalanche conditions, the avalanche service must provide for this zone also a continuous evaluation of the situation so that the inhabitants may be promptly warned of any unforeseen dangers. Under certain circumstances, parts of white zones are also cut off from their environment by interruption of transportation routes.

Avalanche zone planning is primarily the concern of the political precincts and they must also make the decisions regarding admissible risks for the various zones. The creation of avalanche zone plans must be made possible on the basis of legal principles. Up until the present in most cantons, there is a lack of proper planning laws which would provide for the introduction of the avalanche zone plan within the framework of local and regional planning. However, many building laws contain regulations designating building-prohibition zones so that on the basis of these regulations it is possible to designate avalanche zones. In exceptional cases, a precinct can also appeal to the "general police clause" according to which the precinct authority is responsible for undertaking all measures required for protection of the community from dangers in the form of floods, fire, landslides, avalanches, or epidemics.

The avalanche zone plan creates public law limitations which relate to the right to freely dispose of real estate. From this no compensation claims can be inferred since the agencies involved are forces of nature.

The avalanche zone plan must be approved by the precinct. The cantonal specifications also require as a rule approval upon the part of the federal government. The presence of a piece of property in either the red or the blue zone is to be recorded in the property register; for endangerment from avalanches is an important constituent of the real estate description. Only by the notation in the property register can unsuspecting prospective purchasers be made aware of this danger. In this way, the avalanche risk may be considered to be known to everyone.

Figure 1. Excerpt from the "Sernftal" Avalanche Survey, in the District of Matt and Elm, Cantonal Forestry Office of Glarus, National Map 1:25,000, reproduced with the permission of the Federal National Topographic Office, 31 October 1972.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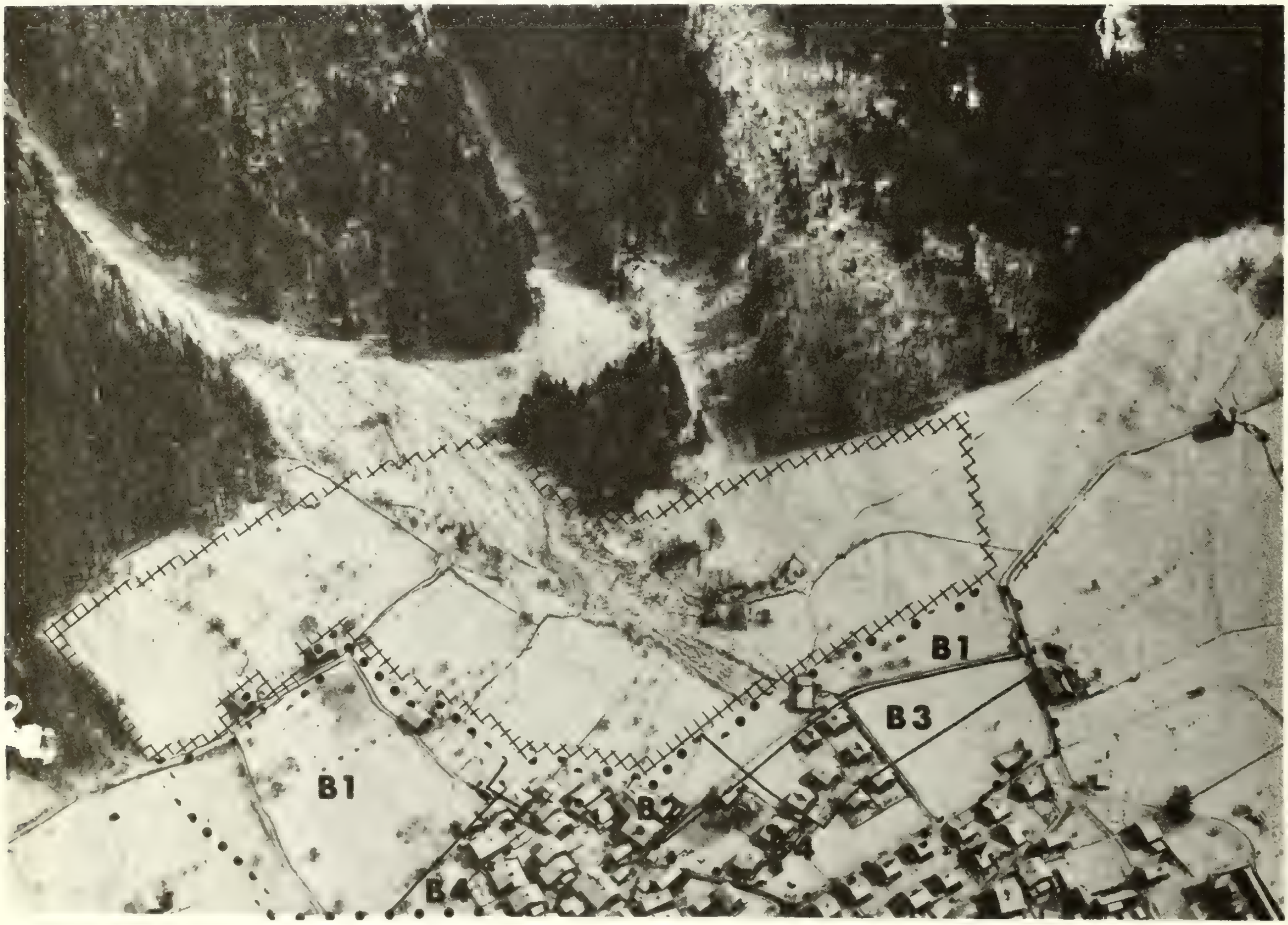
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3.3 Structural Avalanche Protection Measures

Corresponding to their nature and mode of action, two different types of structures are distinguished: structures in the starting zone which prevent avalanches, and structures in the track and runout zones which reduce the damaging effect of descending avalanches. In the starting zone, support structures (Figure 3) and drift structures (Figure 4) are introduced while deflection structures (Figure 5) and retarding structures (Figure 6) take over direct protection of the object in the track and in the runout zone. Both types of structures are also distinguished with regard to their form. They can be set up as massive installations (Figure 7 and 16-18) in the form of heavy structures without perforated surfaces (walls, terraces), as articulated installations (Figures 7-15), composed of various self-contained structural elements (snow bridges, snow rakes, snow nets) and as combined installations consisting of one massive and one articulated component (Figure 7).

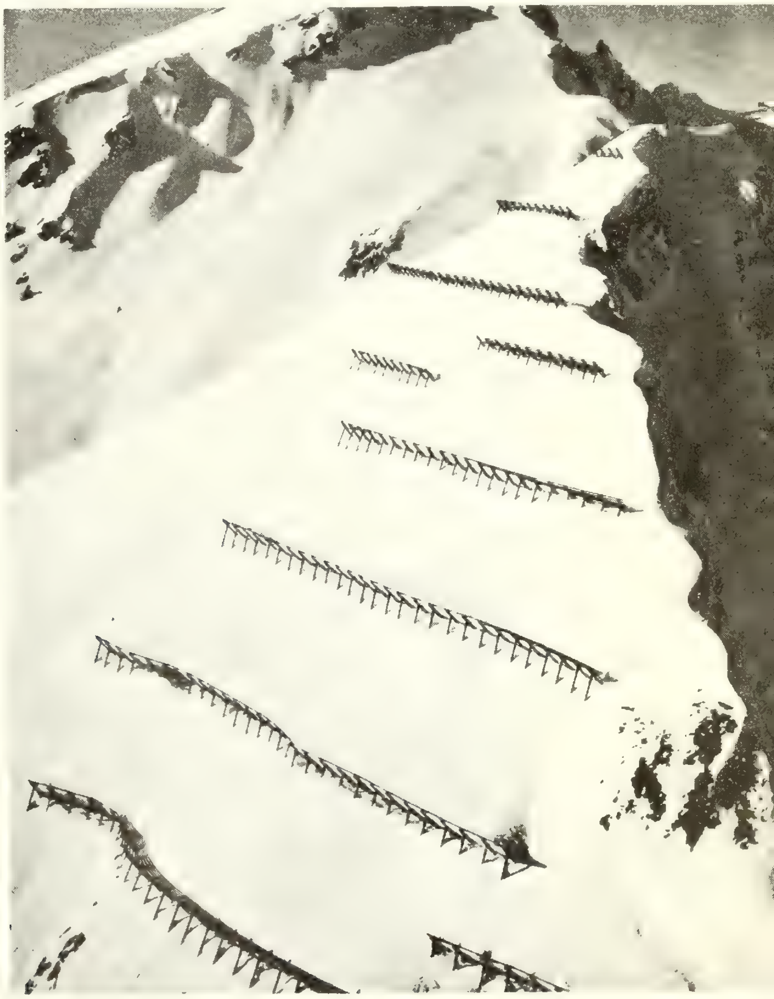


Figure 3. Control structures in the starting zone of avalanches Section 3.3.1); continuous arrangement of articulated supporting structures (photo E. Wengi).

Figure 2a. "Aetzgen" avalanche zone plan of the Ennenda Precinct, H. Oppliger, Cantonal Forestry Office in Glarus, property register plan: the blue zone is subdivided into four subzones having various safety regulations.

Figure 2b. Aerial photo of the "Aetzgenlaui" with plotted avalanche zones (photo E. Wengi).

Key: 1. Red zone (construction prohibited) ▦▦▦▦▦▦▦▦▦▦
2. Blue zone (restricted construction permitted) ⁘⁘⁘⁘⁘⁘⁘⁘

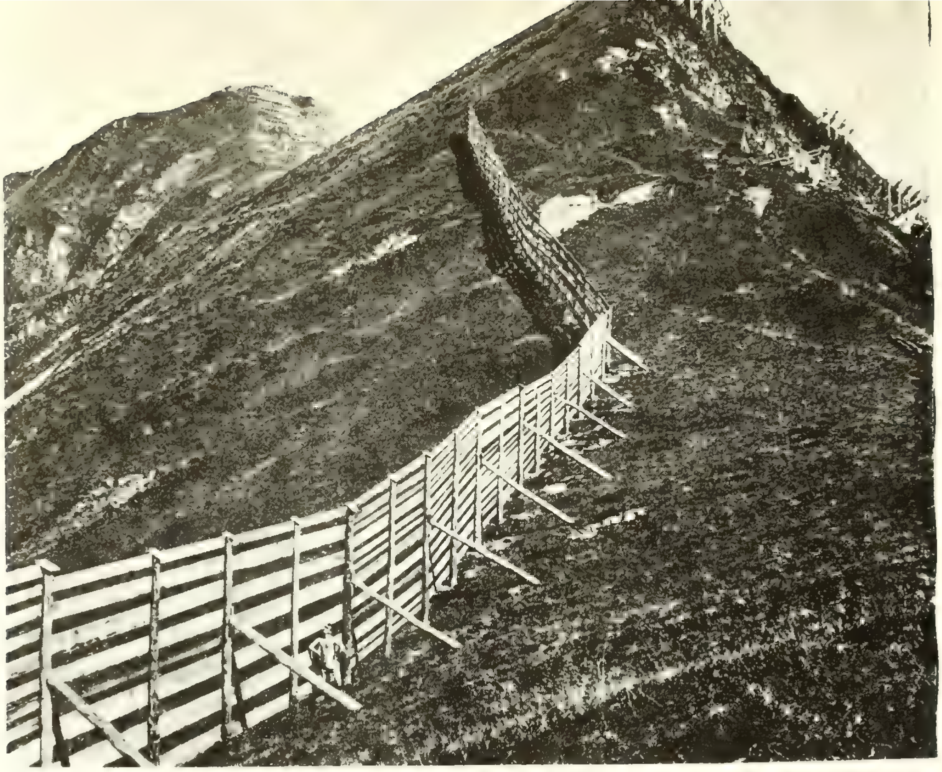


Figure 4. Structures in the starting zone of avalanches (section 3.3.1); snow fence with horizontal boards. When the boards are vertical, one uses the term "snow drift fence" (photo EISLF). [In the United States, there are no simple terms to differentiate between snow fences with vertical boards and snow fences with horizontal boards.]

3.3.1 Structures in the Starting Zones of Avalanches

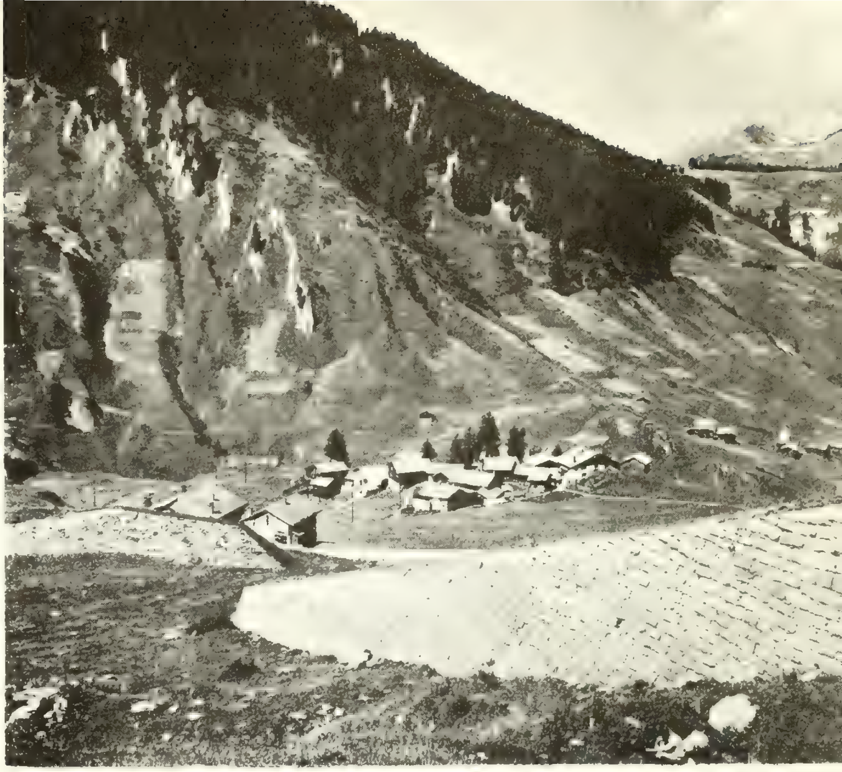
Supporting Structures

Supporting structures support the snow cover in such a way that there can arise either very little snow movement or none at all. Assuming correct dimensioning of the structures, avalanches are prevented in the starting zones. A fully developed avalanche generates forces which, as a rule, cannot be sustained by a support structure. In control-structure regions above treeline, permanent installations are set up which consist of materials having as long a service life as possible (steel, concrete, aluminum). Within the tree zone, where the structure surface can be surrounded by forest, the requirements for durability of the materials are less stringent. It is temporary construction. Immediately after setting up the installation, consisting generally of impregnated wood, the area is afforested with suitable types of trees. After a certain time, the newly established forest prevents the onset of avalanches. In many construction projects we find permanent and temporary installations next to one another: above treeline there are installations of steel and concrete, while in the forest region wood grates and earth terraces are combined with afforestation.

A distinction is drawn between continuous (Figure 3) and broken (Figure 8) arrangement of supporting structures.

Continuous arrangement consists of long, horizontal series of structures which extend over the entire breadth of the terrain which is to be controlled. The lines of structures are interrupted only by parts of the terrain which are safe from avalanches. The broken arrangement displays intermediate spaces in the horizontal lines of structures. Depending upon the arrangement of the structures, a distinction is made between broken-interrupted and broken-staggered or a combination of these two possibilities. The arrangement of the structures is guided by topographic conditions in the construction region, the types of structures and the significance of the objects to be protected, taking into account the admissible risk.

Figure 5. Measures taken in the track and in the runout zone of avalanches (section 3.3.2). Guidance and deflection walls of back-filled dry masonry for the protection of a dwelling (photo E. Wengi).



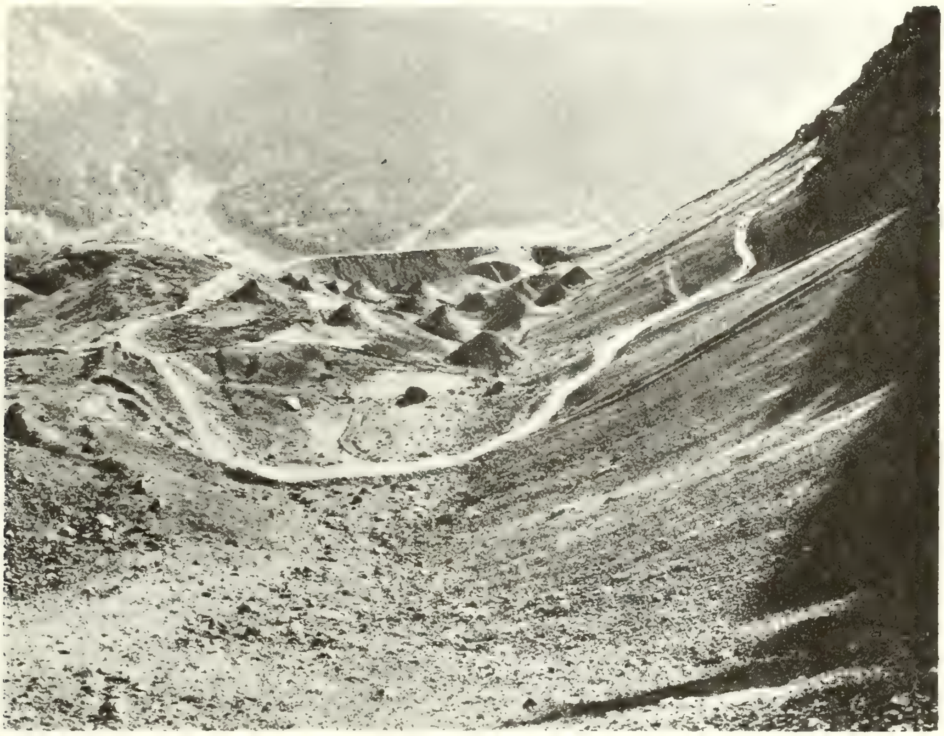


Figure 6. Measures taken in the runout zone of avalanches (section 3.3.2); retarding mounds with trap-dike; the retarding mounds divide the avalanche into many small arms and thus reduce their energy of motion so that the avalanche is brought to a standstill by the trap-dike (photo E. Wengi).

The types of supporting structures are: snow bridges (Figures 9-12), snow rakes (Figures 13, 14), snow nets (Figure 15), avalanche fences[1] (Figure 7), walls (Figures 7, 16, 17), and terraces (Figure 18). The most varied materials are suitable for construction of these installations, such as steel (Figure 9), concrete (Figure 11), wood (Figures 10, 14), wire cable (Figure 15), aluminum (Figures 12, 13), natural rock (Figures 7, 16), wire gravel baskets in conjunction with natural rock (Figure 17), and earth (Figure 18).

Snow Drift Structures [wind-blown snow]

By utilizing wind forces, snow deposits can be influenced so that the formation of great mounds is hindered and the snow cover is favorably influenced mechanically (formation of pits, snow deposit outside starting zones). In exceptional cases, the break-up of snow mounds can be the impulse which triggers avalanches. When the formation of such a mound has been prevented by a snow drift structure, the avalanche path is thereby rendered safe. However, as a rule, drift structures are combined with support structures to modify the snow deposit in the starting zone of an avalanche by introducing snow drift installations in the form of massive snow drift walls and snow drift dikes or by means of articulated types of installation such as solid snow fences (Figure 19), wind baffles, snow fences with horizontal boards (Figure 4), or snow fences with vertical boards. In this way under certain circumstances, extreme depths of snow, for which it would hardly be possible to construct supporting structures, can be reduced to a controllable magnitude.

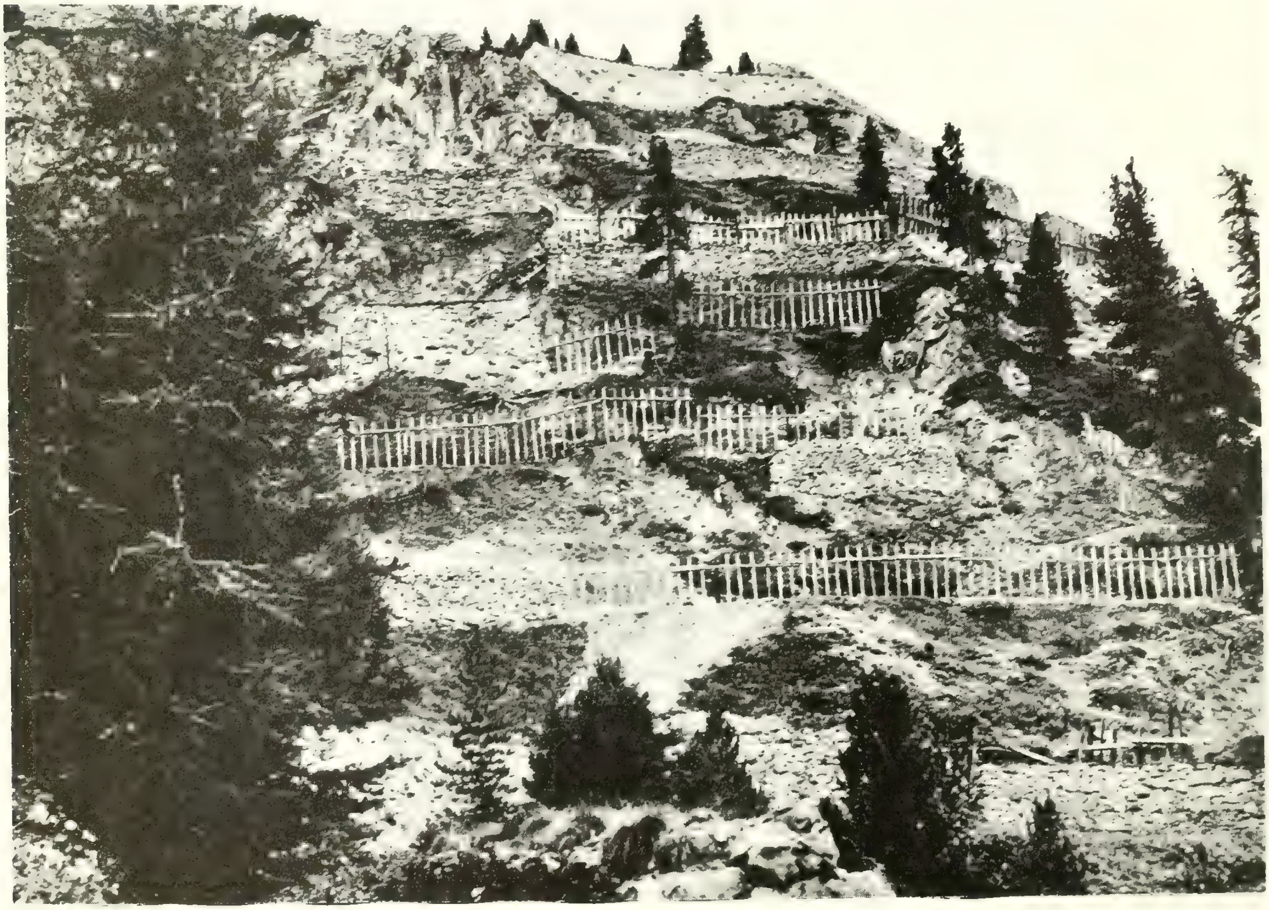


Figure 7. Distinguishing structures according to their form; walls are massive installations without perforated surfaces, avalanche fences are [vertical] articulated installations; in part both forms are combined: walls with superimposed avalanche fences (photo EISLF).

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[1] The term Schneehaege refers to a vertical fence-like supporting structure. Hereafter, we will call it an avalanche fence and reserve the term snow fence for structures used to control blowing snow.

Figure 8. Structures in the starting zone of avalanches (section 3.3.1); broken arrangement of articulated supporting structures (photo E. Wengi).

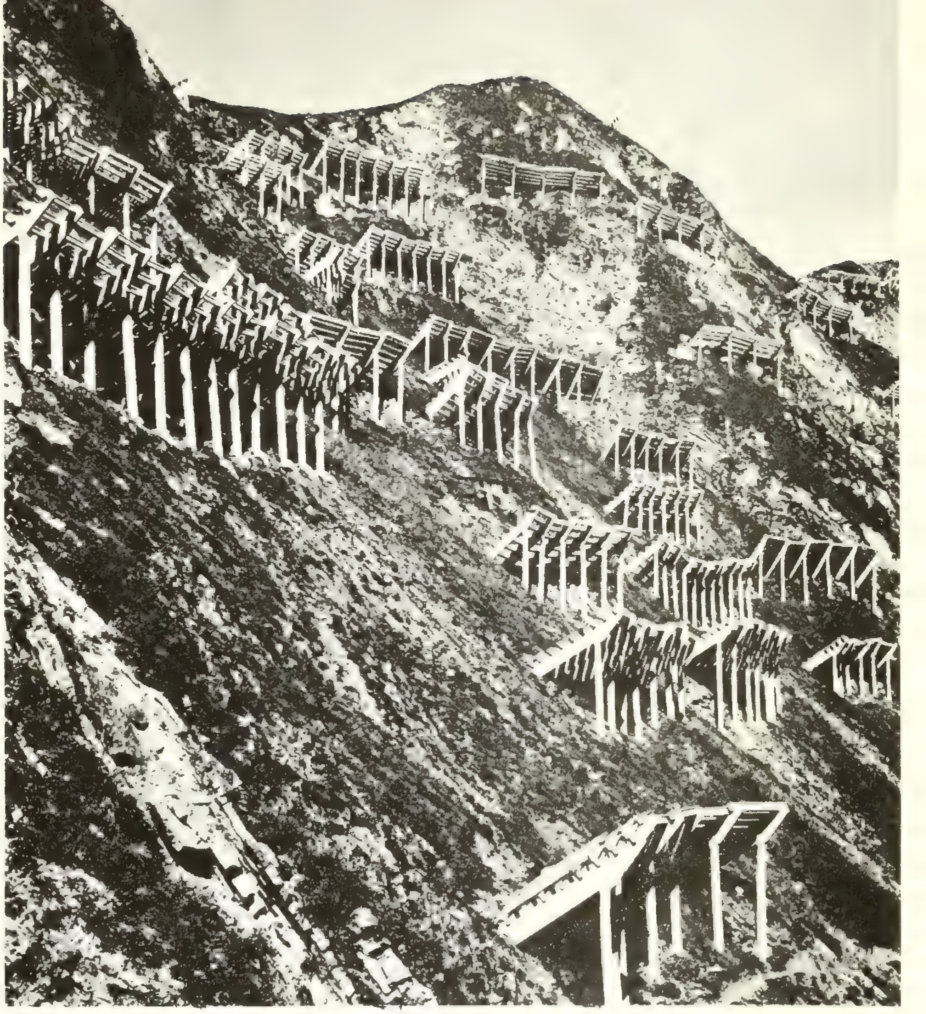

Figure 9. Snow bridge; the beams of the compression grid are horizontal, supports and joists are anchored in the ground (concrete foundations installed on the spot or prefabricated elements, called base plates, are buried in the ground). Steel work of the Austrian-Alpine Montan Company (photo H. Oppliger).

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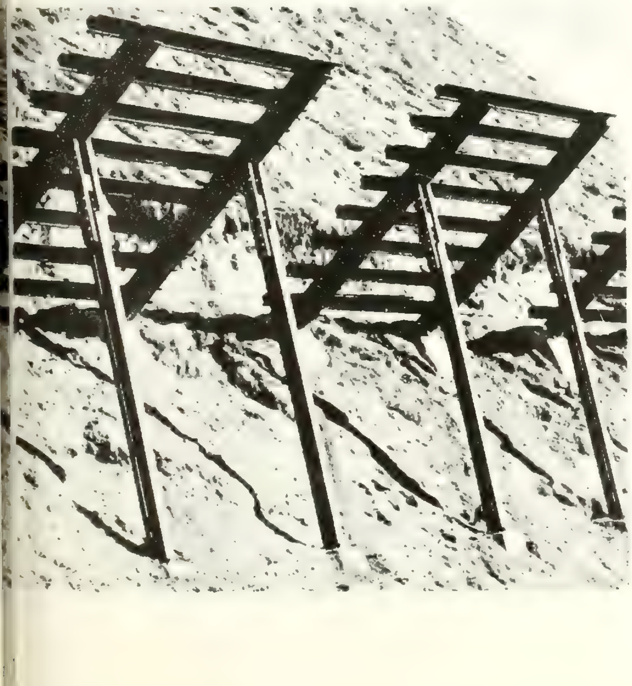


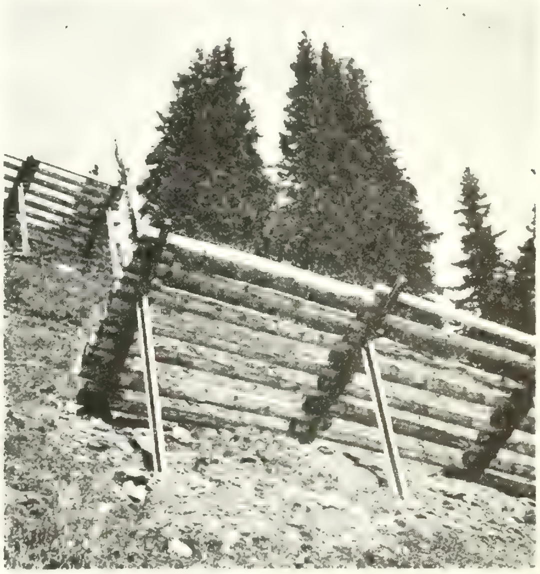


Figure 10. Three-element snow bridge; supporting structures made of railroad rails, grid consists of impregnated fir wood (photo E. Blumer).

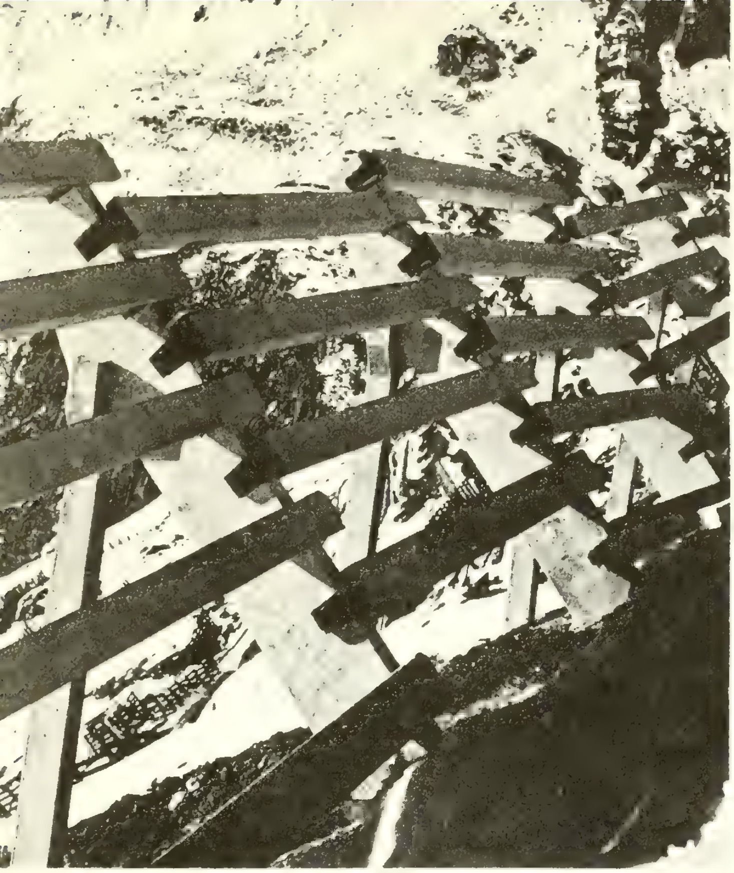


Figure 11. Multi-element snow bridge of prestressed concrete produced by the Prestressed Concrete Company (VOBAG) (photo A. Roch).

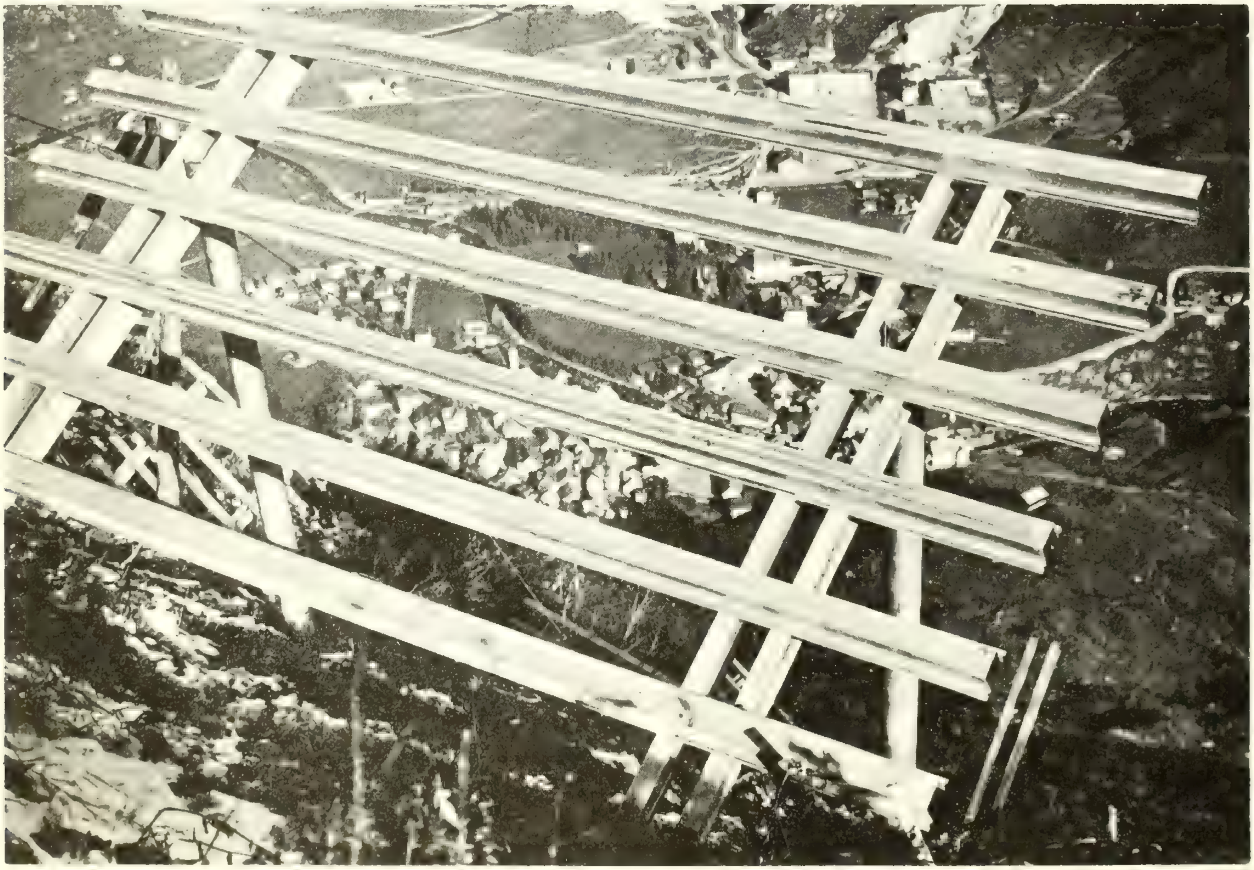


Figure 12. Single-element light metal snow bridge of the Aluminum Industry Company (AIAG) (photo H. Frutiger).

3.3.2 Measures To Be Taken in the Track and Runout Zone of Avalanches

In many cases, the onset of an avalanche cannot be prevented or can be prevented only at disproportionately high cost. Here deflection and retarding structures make possible the protection of important objects. Deflection structures consist of walls (Figure 5) or dikes which change the direction of the moving avalanche and deflect it from the object to be protected. Also included among deflection structures are galleries (Figure 21), splitting wedges (Figure 22), and inclined terraces (Figure 20) which lie directly in front of the protected object. Retarding structures shorten the extent of the avalanche and thus prevent the avalanche from penetrating into the endangered zone. This purpose is served by trap-dikes (Figure 6), trap-walls, retarding mounds (Figure 6), and retarding wedges.

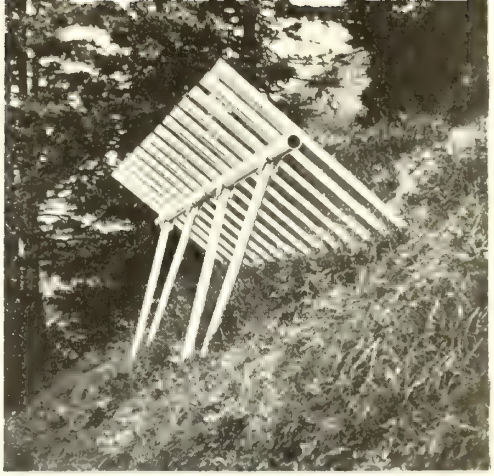


Figure 13. Snow rake; the beams of the supporting grid are perpendicular to the slope, aluminum rake of the AIAG. [Beams of a snow rake are usually erected 15° downhill from the perpendicular to the slope] (photo H. Oppliger).

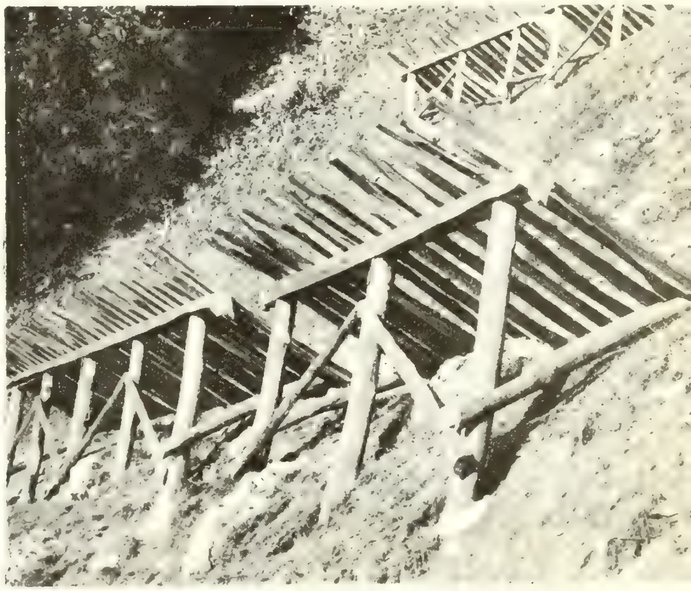


Figure 14. Snow rake of wood; temporary supporting structures; grid, supports, pinscers [Zangen], and swiveling beams consist of chestnut wood, the stringers of fir wood covered with aluminum sheet and the ties lying on the ground are made of railroad rails (photo H. Oppliger).

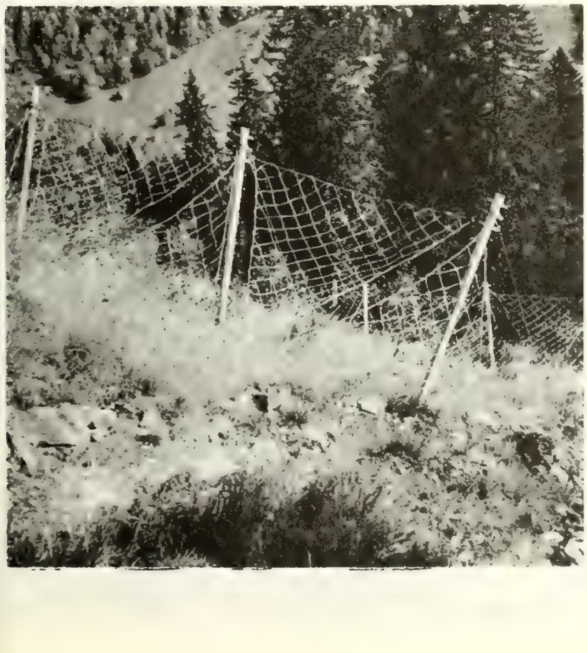


Figure 15. Multi-element snow net of the Brugg cable installation; the "compression grid" consists of wire cable nets hanging on swivel supports. Snow nets are light and capable of resisting rock impact (photo H. Oppliger).

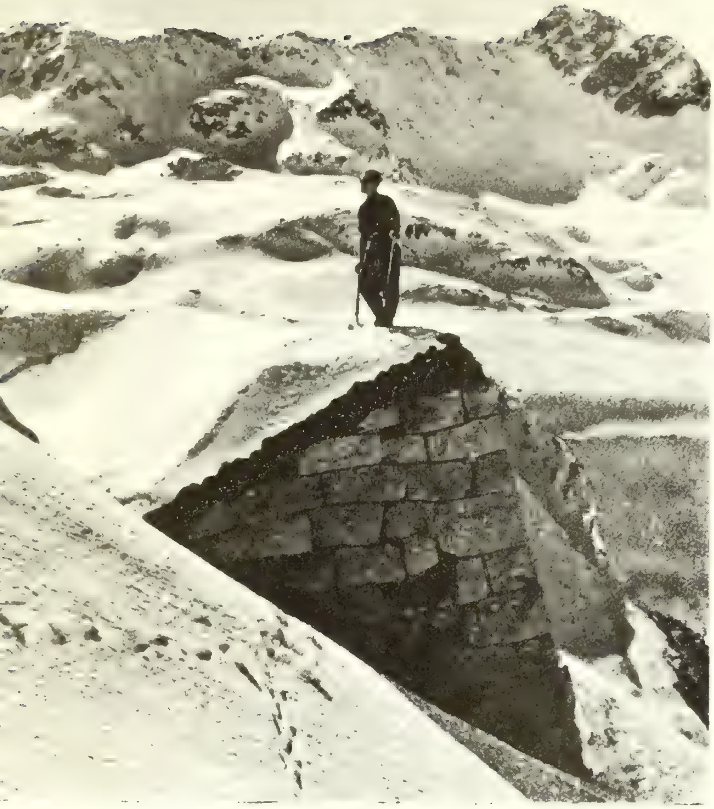


Figure 16.

Back-filled wall of broken stone covered with earth (photo P. Nipkow).

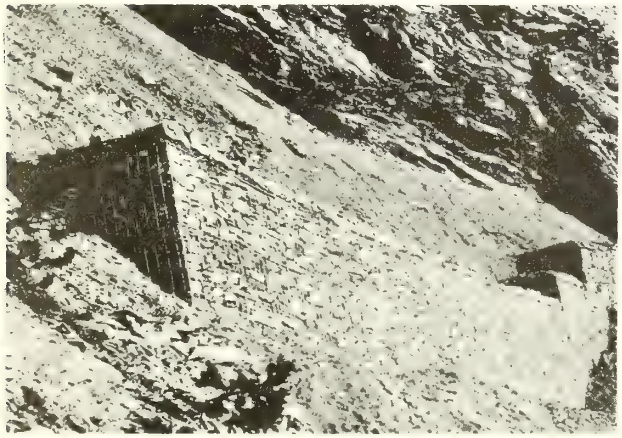
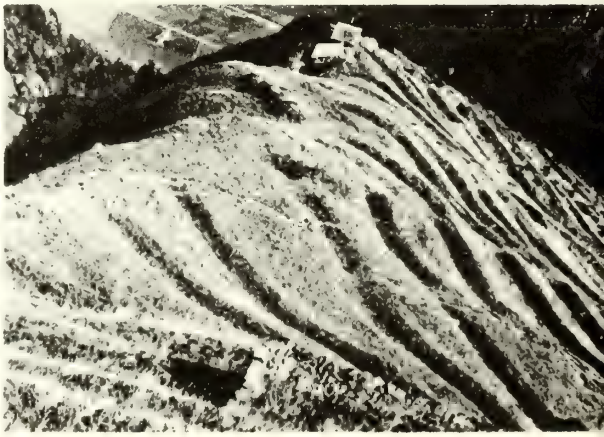


Figure 17. Wall consisting of broken stone and wire gravel baskets [Gabion]; by using woven wire containers it is possible to employ the rock material which often becomes available in great quantities (excavated in the construction of articulated supporting structures) for the construction of walls and wall terraces (photo E. Schildknecht).

Figure 18. Securing a steep slope with earth terrances in an old project; today earth terrances are introduced mainly to protect afforestations against creeping and gliding snow (photo R. Fehr).



In inhabited avalanche zones, which cannot be effectively protected by supporting structures or by direct protective measures, avalanche bunkers or avalanche cellars take over the protection of the endangered inhabitants. These are avalanche-proof rooms which may be resorted to in the case of acute avalanche danger when an evacuation is no longer possible. These dugouts must be so constructed that they also guarantee survival in the event of complete burial. It must also be possible for all endangered persons to reach them rapidly and without risk. Often avalanche cellars are created as additional or quickly available measures in combination with structures in the starting zone or in the track.

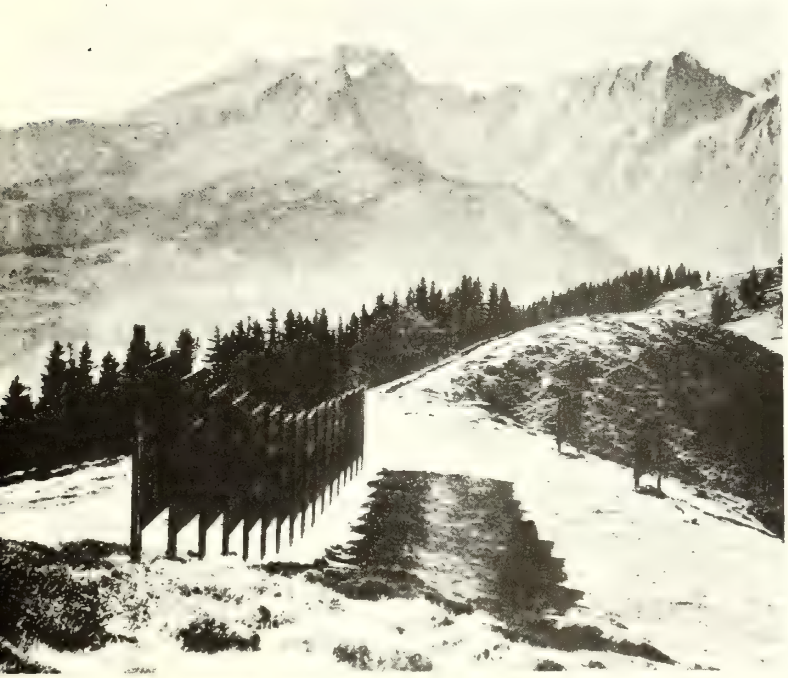


Figure 19. Snow drift structures; solid snow fence consisting of concrete-covered railroad rails and impregnated fir boards (photo E. Blumer).

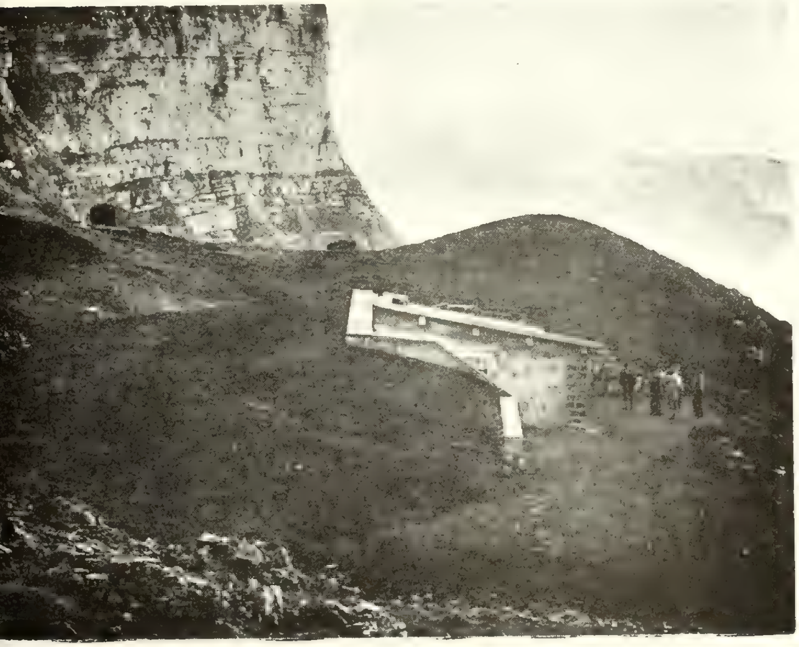


Figure 20. Inclined terrace; the back wall and the roof of the building are reinforced; the avalanche flows over the terrace and the building (photo E. Blumer).

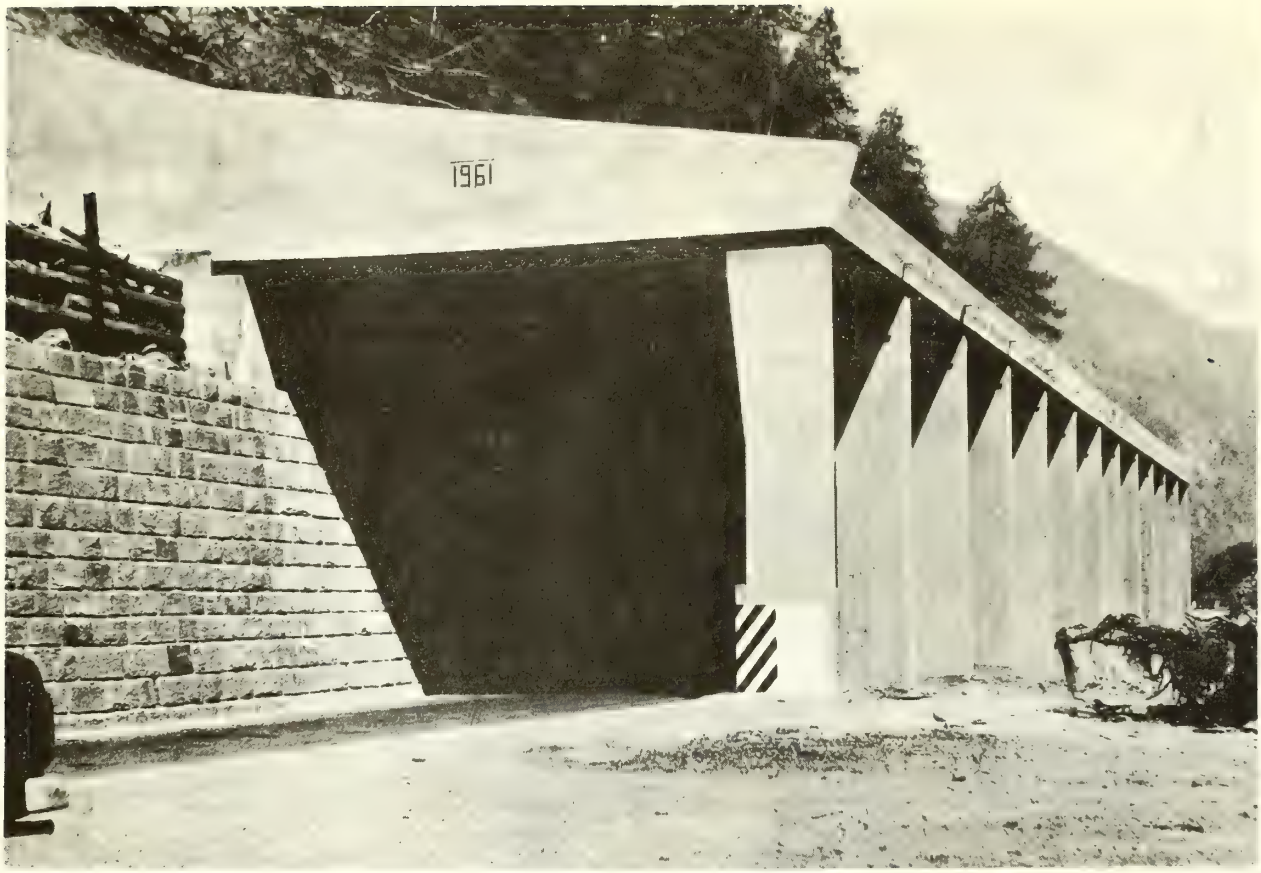


Figure 21. Avalanche gallery of reinforced concrete to protect a road (photo EISLF).

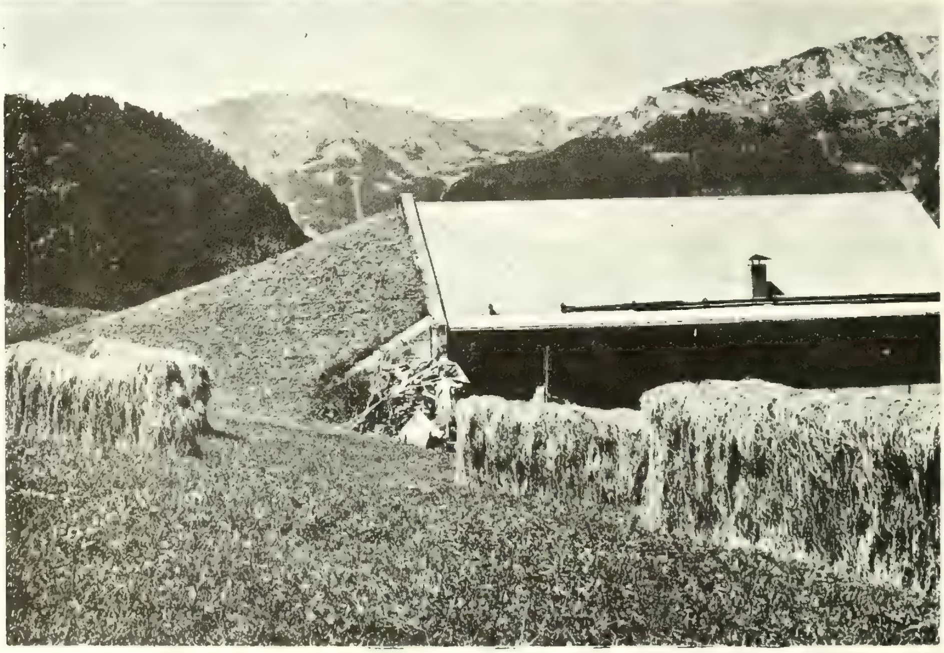


Figure 22. Splitting wedge; reinforced concrete wall with wedge-shaped earthen backfill protecting a stable (photo E. Blumer).

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[1] The Avalanches of the Swiss Alps.

[2] The Avalanche Damage in the Swiss High Alps in the Winter and Spring 1887/88.

[3] Table of Technical Terms for Avalanche Control Structures, Supplementary Instruction No. 3 of 30 November 1953.

[4] Legal Questions Establishing Avalanche Zones in Which Construction is Prohibited.

[5] Avalanche Control Structures in the Starting Zone, Guidelines of the Federal Forest Inspectorate for Supporting Structures.

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IV. HISTORICAL BACKGROUND OF SWISS AVALANCHE CONTROL CONSTRUCTION (Hans Frutiger, Weissfluhjoch/Davos)

There are several reasons for illustrating the development of Swiss avalanche control projects by the example of Davos. Here may be found a great selection of various types of control structures. In addition, the most varied forms of avalanche protection are placed at the service of the safety of this tourist center. These include not only structural protection, but also other possible measures such as the avalanche zone plan, warning service, closures, and artificial triggering of avalanches. In Davos, the development from a mountain farming hamlet to health resort and later into a winter sports center began somewhat more than 100 years ago. The stretch from Landquart to Davos was the first subsection of the Rhaetian railroad and several large mountain railroad projects coincide in time with the beginnings of so-called "technical" avalanche control construction. The development of the latter was strongly influenced by the avalanche problems of these railroads. Moreover, the activity of important pioneers in avalanche control construction was closely bound up with Davos. Since 1934, avalanche research has been conducted on the Weissfluhjoch in the region of Davos so that naturally it has also been possible to study the problems of control structures more thoroughly than might have been possible elsewhere.

There exist numerous indications that in the course of the 17th to the 19th centuries, because of increasing deforestation, there was a sharpening of avalanche endangerment in the valleys. Among other evidences, there is a hint of this in the very old edicts designed to protect forests above settlements. The Davos interdicts cover the period from 1535 to 1777. In the regions of the Valais, which also includes Davos, the decimation of the forest can be proven with specially good reliability. It is not an accident that valleys settled by Valaisans frequently have the reputation of being avalanche valleys. A classic example is St. Antoenien where on the deforested sunny side, without exception, every individual farm has its own avalanche protection usually in the form of a splitting wedge. A well-known example of direct avalanche protection is the Lady Chapel at Davos. The chronicler Flury Sprecher reports: "In 1602 on 16 January, on a Saturday night, at 2400 hours, after it had been snowing for 3 weeks and the snow had reached a depth of over 12 shoes [sic], all at once powerful snow avalanches broke loose in Davos in several locations so that mountain and valley trembled and roared. Entire larch and pine trees with their roots, much earth, and stone were torn away, the Lady Chapel with 70 houses and farm buildings were demolished or carried away and buried with all the inhabitants in the snow." And Jakob Gaudenz: "Anno 1817, on 28 February, here near the Lady Chapel, a frightful snow avalanche came down from the Stafflerberg, covering and surrounding the church with snow up to the roof, so that it was necessary to enter through the window near the organ." Apparently the church had been equipped with a splitting wedge after the accident of January 1602. The latter withstood the Frauentobel avalanche of 25 January 1968 again, but did not prevent a crack in the long side of the building. We do not know how far back in time this type of avalanche protection -- known in modern terminology as "direct object protection" -- extends. It must be assumed that structural control of avalanches had its inception with the settlement of the mountain valleys. Numerous haystacks, herdsmen's huts, and stables had to be protected from the outset by means of inclined terraces at the back and by splitting wedges. Such types of avalanche protection may be found in most alpine valleys. Correspondingly great, too, is the number of variety of names such as "Ebihoech," "Ueberhoh," "Lauistock," "Schanze," "Pfeil," "Abwurf," "Triangel," "Spiessegg," "Pfanneir," "Schneefirst," and "Schirmmauer."

Also, modern designs for direct object protection such as avalanche dugouts and galleries have been known for a long time. In Saas Grund, probably after the avalanche disaster of 1849, so-called avalanche crypts were introduced. These are underground chambers in which the inhabitants find safety during avalanche danger. Between Lavin and Guarda, vaulted niches were constructed along the old road as avalanche dugouts for travelers. Also, galleries have been constructed in early times for the protection of alpine streets and roads. In the beginning of the 18th century, gallerys were introduced into the most avalanche-exposed parts of the mule track over the Spluegen in the Val Cardinello. The Bernhardin route which had been built in 1823 from the very outset was furnished with avalanche galleries on the south side in the Val San Giacomo. Around the year 1805, the Kaltwassern gallery was constructed on the Simplon. This beautiful masonry structure was compelled to yield in the sixties to the modern enlargement of the pass highway. In the year 1871, the Davos community obtained the first avalanche gallery in a place called Brombenz on the Zuegen road, which had been built between 1870 and 1873. In a report from the year 1899 we find: "At each heavy snowfall the snow slides off and then frequently fills up the road on both sides of the gallery. The place also has a bad name with the drivers." Eighteen years earlier Coaz had written: "In constructing galleries care should be taken to make them long enough because otherwise they give poor protection and, whenever both ends are buried, cannot be used or can be used only after the entrance and exit have been opened." Both these observations have been cited here because even in the most recent times, the same old mistake has been repeated.

In March of the year 1818, the silver mine was leased to Johann Hitz of Klosters. Before renewal of the lease in 1822, the Bernese forester Karl Albrecht Kasthofer was commissioned to give an expert opinion regarding the Davos forests. This was the immediate occasion of the mountain journey which he carried out in the interest of forestry science in 1821 over the Gotthard and Bernhardin [passes] to Davos. In the year 1816, he had published the "Notes on the Forest and Ranges of the Bernese Oberland." There he also speaks of avalanche control projects: "In the neighboring Valais here and there on steep mountainsides, where snow avalanches form readily, the country people have fixed posts of larch into the ground and this simple device prevents the development of avalanches." Also in other localities, early attempts were made with very simple equipment to prevent the onset of avalanches. On the Piz Cluenas, after the disaster of the year 1817, horizontal ditches were also excavated in order to anchor the snow cover. We also know that after the avalanche disaster of 1756 in Geschinen in the upper Valais, permission was granted by the bishop for work to be performed on Sundays and holy days to renovate the ditches in Birch, which therefore must have been built earlier. Evidently at that time, this form of avalanche control was not yet known in the Bernese Oberland, for Kasthofer continues: "The inhabitants of our valleys have suffered for centuries from this frightful natural phenomenon without ever having sought a means of preventing its occurrence. The maintenance of those forest districts which are designed to oppose the development of the destructive natural phenomena which have just been described, and the cultivation of forests to this end is one of the most difficult tasks of forestry science in the mountain highlands and indeed this is not only because of the great obstacles which are presented by the very nature of these rough regions and which not infrequently render any kind of forest cultivation or careful forest preservation impossible; these obstacles are made still greater as a consequence of the claims made by private persons upon the ownership and use of those mountain slopes which must be at the free disposal of forestry police and water police for the purpose of preventing avalanches, rock falls, and earth cave-ins." Thus, Kasthofer invokes the prevention of the occurrence of avalanches -- which in today's terminology is called "structural control of avalanches in the starting zone." Kasthofer together with a well-known Graubuenden forester, thereby introduces a new epoch in avalanche control construction. Since in the beginning it was primarily a matter of maintaining and reconstructing the protective forest, avalanche control became the task of the Forest Service and has remained so to the present.

About the middle of the 19th century, some events occurred which were of importance for the science of forestry and for avalanche control. The year 1834 brought devastating inundations of water. The consequences of forest destruction, which was in turn a consequence of salt-works operations, smelters, and overgrazing of mountain pastures, were now becoming apparent. In 1843, the Swiss Forest Association was formed; its foundation goes back to Kasthofer. One of its leading members was Elias Landolt. As the first professor of forestry science at the newly founded Swiss Federal Institute of Technology, in 1858 he was commissioned by the Federal Council to give an expert opinion regarding the state of the mountain forests. The comprehensive final report was printed in 1862 and disseminated in large numbers. On 27 October 1864, the forest association submitted to the Department of the Interior the following request: "It is recommended that for the promotion of forestry science an annual credit of 20,000 francs be introduced into the federal budget." On 12 March 1865, the forest association was able to declare in a letter to the governments of the mountain cantons: "The Federal Parliament has recognized the efforts of the association and their economic significance and has reserved for the association, with the given object, a credit of 10,000 francs for the year 1865." In this we recognize the antecedent of federal subsidies without which today's avalanche control would be unthinkable. The second great water emergency of the autumn of 1868 triggered action in this area. Forester Emil von Grayerz write in November 1868; "Now or never the federal government and the cantons will lend a hand to put a stop to the further devastations which threaten us from the mountains. There really remains no other hope and source of aid other than the federal government and we would really be astonished if this federal government, despite the cantonal sovereignty, had not the force, the power, and the will to undertake something which could protect the whole country from further devastation and impoverishment." Another 2.5 years passed before on 21 July of the year 1871, there was formulated the "Federal Resolution Concerning Approval of a Federal Contribution for Torrent Control and for Afforestation in the Alps."

The year of 1871 is also significant for our study in still another respect. In the period from 1851 to 1873, Johann Coaz was the forest inspector of Graubuenden. Building on the preliminary intellectual work of Tschokke, Kasthofer, and the forest association, he was able to convert many ideas into actuality. He went to work with unheard of energy. He had already had supporting structures built in 1868 on Motta d'Alp in the lower Engadine, and he himself called it the "first structural control of avalanches carried out under engineering supervision in the Swiss Alps."

On 26 July 1870, the Alberti Torrent, which was at that time still without any structures, produced a great flood and devastated the surroundings of the cemetery. Coaz, presumably still in the year 1871, had urged the federal district forester to notify him of places where afforestations were necessary or desirable and had submitted to the government a tabulation of such places. Davos is represented there by two projects, namely, with the afforestations of the Alberti Torrent and of the avalanche path in St. John's wood. With its 56 hectares the Alberti is the largest afforestation in the area. There soon followed a further afforestation project for the watershed of the Gugger Torrent with 36 hectares. How great the afforestation activity at that time was can be gathered from the figures for the upper Engadine where in the years 1875 to 1934, on an area of 681 hectares, 5.34 million seedlings were set out. Table 1 shows what was accomplished in Davos.

In these projects, the starting zones of avalanches were built up almost exclusively with terraces and post installations. Figure 1 shows the standard procedures at that time.

With the help of these installations, numerous afforestations were promoted. But it had long been recognized that it was not the case that "this simple means prevented the occurrence of avalanches," as Kasthofer had expressed himself in 1816. Today, terraces and post installations are merely an auxiliary device for the protection of afforestation, particularly as a protection against gliding snow. Since 1955, their suitability has been under test on extended experimental areas of the Federal Institute for Snow and Avalanche Research on the Dorfberg near Davos.

The avalanches which devastated Davos on 23 December 1919, were the occasion for further construction projects. For the most part, these extended far above the upper tree line where afforestations were no longer possible.

Table 1. Afforestations and Construction Projects in Davos 1874-1920

Name of Region	Area ha,	No. of Seedlings	Earth Terraces, Length, m	Rows of Posts	
				No. of Posts	Length, m
Albertitobel	55.8	331,000	7,398	?	?
St. Johannwald	2.8	5,220	437	729	510
Brombenz	1.5	5,300	--	75	44
Haehlzuegli	2.2	9,100	183	1,130	792
Schatzwald	36.3	103,315	980	1,971	1,380
Waldenmaehder and Hohruefeli	3.3	6,600	--	7,227	5,060
	101.9	460,535	8,998	11,132	7,786

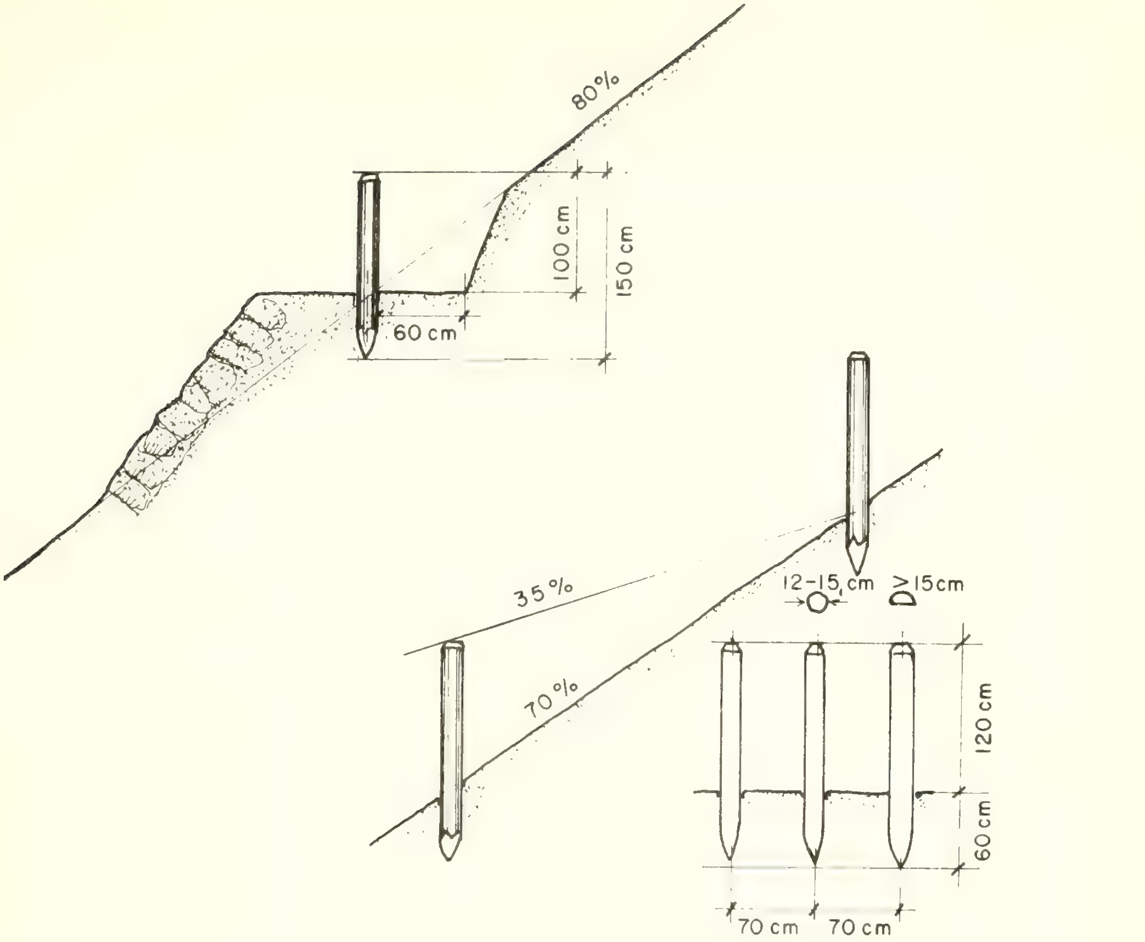

Figure 1. Top: standard procedures for earth terraces (beams) and rows of posts for the "Guggerbach-Schatzalp" afforestation near Davos; autumn 1901. Below: standard procedures for rows of posts for the "Waldenmaeder" afforestation near Davos; August 1910.

On the Schiawang and Dorfberg in the years 1920 to 1924, a total of 7,217 running meters of supporting structures were erected, predominantly walls, wall terraces, mixed terraces, and earth terraces. The building material, broken stones and earth were obtained on the spot or in the vicinity. Wood or even steel was employed only exceptionally for a few snow rakes in narrow couloirs. The structures, consisting principally of hewn stone, are called massive structures to distinguish them from the articulated type, e.g., the snow rake. In Switzerland between 1876 and 1938, about 1,000 km of supporting structures were erected, of which 95 percent were massive structures.

It soon became apparent that the broken stone wall construction was less durable than had been assumed. On the Schiawang and Dorfberg, after only a few years, substantial signs of disintegration appeared, particularly in the mixed terraces. Only 6 years after what had been thought to be the conclusion of the construction work it was necessary to set up a project for the alteration of the mixed terraces into wall terraces and for more extensive repairs on the walls. Improvement and enlargement operations extended into the year 1944.

A further inadequacy became apparent: the terracing of the slope did not suffice as a support for the snow cover whenever unfavorable conditions were present. Sufficient thought had not been given to the leveling effect of the wind upon the snow deposits and to the differential snow cover build-up (compare Figure 2); avalanches broke loose also in the defense areas.

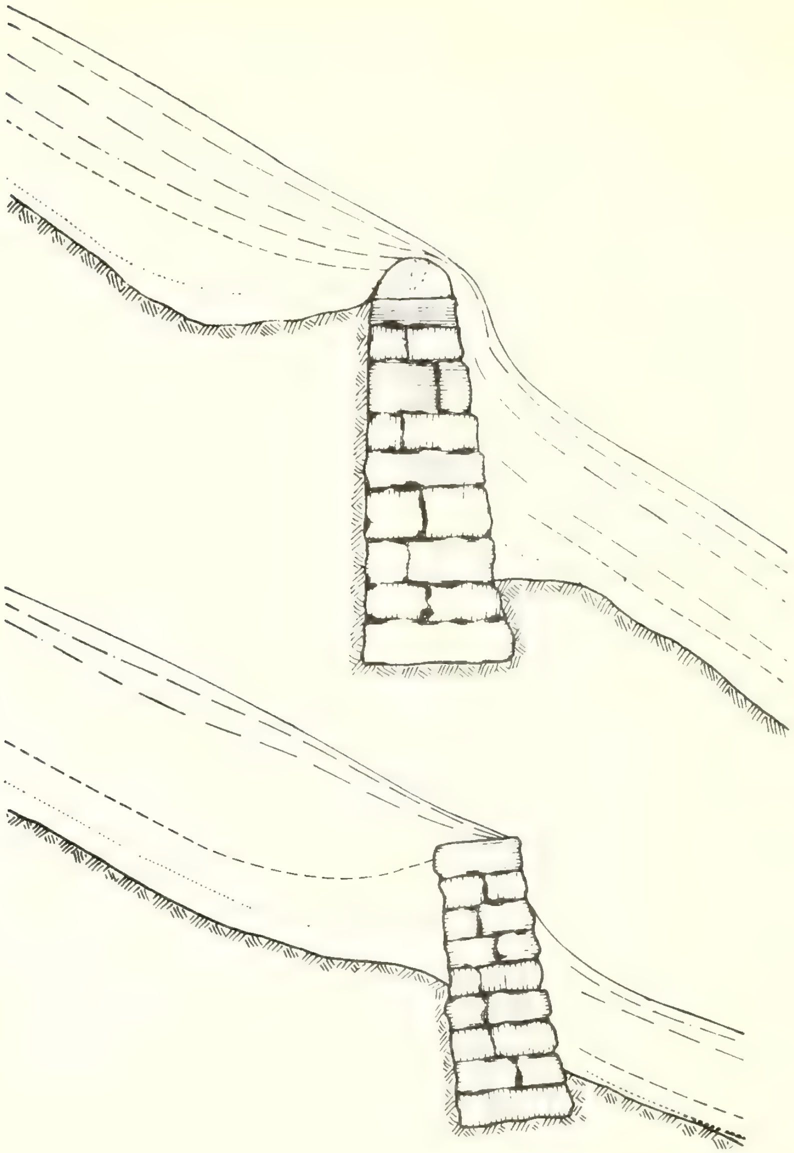

Figure 2. Leveling effect of the wind upon snow deposition among massive supporting strucures (after E. Eugster, 1938, p. 72). Top: wall terrace Alpetta, 2,230 m above sea level; 30 January 1930. Bottom: free-standing wall, Alp Gruem-Cavaglia, 2,100 m above sea level; 21 January 1930.

The years between 1920 and 1940 are characterized by a new pioneering development. The federal forest inspector F. Fankhauser II had continued in the twenties to be a zealous proponent of avalanche control by means of terraces, although Vincenz Pollack, who had made penetrating and thorough studies of avalanche construction projects along the Arlberg road, had already in 1907 cast considerable doubt upon the effectiveness of such "earth banks and stone banks" and "stepped excavations." Coaz was also aware of the inadequacy of such structures, for in 1910 he wrote: "The so-called 'surface layer avalanches' constitute one of the greatest dangers for any control construction, and hence we have every reason to prevent the development of such avalanches. One method of doing this is to erect the installations taller than usual so that wherever possible they extend into the upper part of the snow cover. This can be accomplished to a certain degree; however, the associated costs should not be allowed to range too high." Knowing this fact, progressively taller structures have been built in the Obergesteler Galen. Hess wrote in 1936: "When these installations, too, turned out to be inadequate and snow slides recently ran over them, it became necessary to build still more effectively. The last wall type attains a total height of 8-9 m, of which 6-7 m of useful height extend above the slope."

A certain malaise became evident in structural control of avalanches. This becomes clearly evident in the "Experiences With Structural Control of Avalanches," which Emil Hess, who was then forest inspector, published under contract to the forest inspectorate in 1936. In the introduction he asserted: "Considering the importance and the many-sidedness of the problems and their effect upon the public economy of the mountain regions it would have been worthwhile, even a long time ago, to gain closer knowledge of avalanche formation by means of systematic observations and experiments, in order to obtain generally valid principles for the installation of structures." He remarks further that Switzerland, with respect to exact snow research, had stayed behind the neighboring countries and that means were lacking for large-scale research studies. However, the latter were already in progress. In the year 1931, the Federal Snow and Avalanche Research Commission had been founded, and in 1935, a team of researchers had started the work in Davos. In the first winter, the work was still carried out down in Davos and after 1936 up on the Weissfluhjoch. As early as 1939, results of decisive importance for avalanche control construction were published in in a comprehensive work entitled "Snow and Its Metamorphism." R. Haefeli had succeeded in carrying out a snow pressure computation which became the basis for the design of modern, articulated supporting structures. In the region of the Weissfluhjoch, it was possible to check the theory by means of snow pressure measuring devices in the form of snow bridges. At the same time, the avalanche-control structures in the vicinity offered ample opportunity to continue intensively the winter observations which had already been begun earlier in other localities. The already mentioned inadequacies were also confirmed in the Dorfberg project which had been strengthened in the years 1947 and 1948 by the erection of snow fences and snow rakes between the terraces. During the supplementary operations on the Schiawang, the idea was conceived as early as 1935 of replacing the wooden beams of the snow rakes, which at that time had an almost horizontal supporting plane, with prefabricated, armored concrete beams. Experiments were also carried out with woven wire coverings on the support grates.

In 1942, snow research set up shop in the newly erected institute on the Weissfluhjoch. Its first director, E. Bucher, in 1947 published the "Discussion of Avalanche Defense Works"[1/] and in 1948 there followed the "Contribution to the Theoretical Foundations of Avalanche Defense Construction."[2/] It would take us too far afield here to describe in detail the investigations and conclusions of Haefeli and Bucher, although in certain respects they exercised a great influence upon the technology of the practice of avalanche-control construction. For the further development of structural control of avalanches, there was importance in the requirement that the supporting structures should be built high enough so they would not be covered by snow. In the case of massive structures this was possible only with disproportionately high costs. Bucher came to the conclusion, "that the rake structure erected approximately perpendicular to the slope may be considered a very useful construction element."

There soon followed the avalanche winter 1950/51 and the federal law of 19 December 1951 which brought with it an extraordinary subsidy over a 30-year period in the form of increased federal contributions to afforestation and structural-control of avalanches. For operations in the starting zone and for the restoration of protective forests, up to 80 percent of the cost was borne by the federal government. There were new allocations, over a period of 10 years, of contributions of up to 50 percent to galleries protecting highways and roads and up to 30 percent for the relocation of avalanche-endangered buildings [sic]. This unleased a veritable flood of control projects. The development proceeded with unexpected speed. In the "Contribution to the Study of Structural Types in Avalanche-Control Projects" of the Federal Institute for Snow and Avalanche Research (EISLF) of 1951, the building materials considered were steel, concrete, and wood. In late fall of the very same year the first light metal snow bridges were installed in the "Mattstock"/Amden project and almost simultaneously in January 1952 the Prestressed Concrete Company (VOBAG) made its first contacts with snow research for the purpose of producing snow bridges. In August 1952, there began the installation of the

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[1/] In English as: Technical Translation TT 66 National Research Council of Canada, 6 April 1948.

[2/] In English as: Translation 18 U.S. Army Snow, Ice, and Permafrost Research Establishment [now called CRREL] Hanover, New Hampshire, February 1956.

first VOBAG snow bridges in the "Milez"/Tavetsch project. Along with the snow bridges there then came a basically new type, the snow net. In the fall of 1951, square nets of wire cable from the Brugg Cable Works Company (KWB) were set up in the "Schafberg"/Pontresina project and for the protection of the Maloja road in Sils-Baselgia. In December of the same year, the KWB proposed to the snow researchers that investigations be conducted regarding the suitability of the wire cable net for avalanche defense works and that the design proposals be checked. In the study "Proposals for the Design and Calculation of Net Installations," R. Haefeli in 1954 proposed the triangular snow net and extended the snow pressure calculation to the latter. He saw in the slack trapping surface a particular advantage in contrast to the conventional rigid supporting plane. Within a few years the open structures had developed from the ponderous wall to the extremely slender and light snow net. Now open structures are employed almost exclusively.

In the spring of 1955, E. Hanausek encouraged the Austrian-Alpine Montan Company to develop a steel snow bridge. In late fall of the same year, the first 50 bridges were delivered for avalanche control on the Heuberg near Haeselgehr/Tirol. In close cooperation with the EISLF, which supplied the design criteria, the steel structures were further developed and were soon employed generally in Switzerland also.

In the year 1952, the EISLF installed the experimental project on the Dorfberg near Davos. This permitted continuous observation of the various types of structures with regard to their effect upon the snow cover and with regard to the effect and stability of the various building materials. Here, gathered into the most restricted space, all possible types of structures can be examined.

In response to this rapid development, regulatory measures soon asserted themselves. The federal forest inspectorate, as the supervisory organ of the federal government, which had to carry the major part of the costs of structural control of avalanches issued various directives with the purpose of creating uniform principles for planning structural control of avalanches. On 30 November 1953, the "Table of Technical Terminology for Structural Control of Avalanches" and on 20 May 1955, the "Provisional Guidelines for the Design of Permanent Supporting Structures" were published. In the beginning of 1961, the latter were given definitive form. The use of these guidelines is binding upon all avalanche structural control projects subsidized by the Swiss Federal Government.

Table 2. Comparison of the Lengths of Massive and Open Supporting Structures

Period	Massive Structures m'	Massive Structures %	Open Structures m'	Open Structures %
Davos 1920-1924 Schiawang-Dorfberg	7,045	98	172	2
Switzerland 1876-1938	990,500	95	50,000	5
Switzerland 1938-1966	20,800	18	96,700	82

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V. PRINCIPLES OF STRUCTURAL CONTROL OF AVALANCHES (Bruno Salm, Weissfluhjoch/ Davos)

1. Introduction

"If one compares the relatively short development time of structural control of avalanches with that of other areas of construction, then it is not surprising that structural control in the starting zone, with which we are exclusively concerned here, is still in its period of stormy youth." It was thus that the respected pioneer of snow and avalanche research Prof. Dr. R. Haefeli described the situation in structural avalanche control in the year 1951 [1]. In the meantime, some things have changed. The "storms" have in great part subsided and we have moved into a rather "classical" period. In the past 21 years, the investigation of fundamentals regarding the material properties of snow has been intensively pressed forward not only in Switzerland but also in many foreign research institutes. At the same time, the behavior of avalanche control structures was continuously observed by the practitioners and from this it was possible to draw useful conclusions. The development manifested itself for example in the "Guidelines of the Federal Forest Inspectorate for Supporting Structures" [2], where all insights and experiences accumulated in the course of time are summarized. These guidelines were already in their fifth edition in 1968.

It is not, however, our intention to leave the impression that all problems of avalanche structural control have been solved. There continue to be gaps; occasional, often heatedly conducted discussions among specialists attest to these gaps. Nevertheless, it may be contended that today it has become possible to set up avalanche structural control which guarantees a very high degree of safety. Often the problems now lie more on the political and financial plane and no longer on the technical plane.

2. The Material Properties of Snow

Combating avalanches presupposes a knowledge of the material properties of snow which is as comprehensive as possible. One should clearly understand why avalanches occur, why at this particular slope and not at another. Further, one should also understand how they move, what velocities are attained, and what sort of dynamic effects are to be expected, etc.

First a distinction must be drawn between snow which has retained its original structure, or in other words, as it occurs in the naturally deposited snow cover, and snow whose original structure has been, at least partially, destroyed by fracture processes. The first kind shall be called "natural snow" and the second "avalanche snow," where the latter may be understood to be a thorough mixture of the smallest snow particles with air into a so-called aerosol (compare de Quervain 2, 3).

2.1 Natural Snow

The behavior of natural snow is similar to that of a tough, compressible fluid. In contrast to a rigid body, snow therefore deforms even under the very smallest loads and modifies both its shape (shearing and extension deformation) and volume (volume changes). It is one of the most important problems of snow mechanics to find a relation which shall be as general as possible between stresses and deformation velocities. The very simplest relation between these two quantities is given for the Newtonian fluid in a one-dimensional state of stress by

$$\sigma = \frac{1}{a} \frac{\partial u}{\partial x} \qquad (1)$$

where σ denotes a tensile or compressive stress; a is a constant of viscosity which depends upon the nature of the snow; and u is the deformation velocity in the direction x. Thus the stresses are proportional, not to the velocities themselves but to their changes in the direction of one axis. Hence, we would have to look for the highest stresses in a snow cover wherever the velocities change most markedly. Tests have shown that relation (1) is valid only for very small stresses and deformations. The quantity "a" increases substantially as the stresses increase; in addition, it also depends upon whether σ involves a tensile or a compressive stress (being substantially greater in the case of compressive stresses). Nevertheless, equation (1) is entirely sufficient for our considerations. In addition, it is also valid for pure shear deformations perpendicular to the x-axis whenever the shear stress and shear deformation are substituted in place of normal stresses and normal deformations.

Naturally, relations like (1) are not valid for arbitrarily high stress magnitudes; here the strength of the material sets certain limits. As was the case with viscosity, this strength depends very much, in the case of snow, upon various factors and correspondingly varies between very wide limits. In general, the strength also increases with increasing specific weight. Besides, the compression strength of one and the same variety of snow is just about twice as great as its shearing and tensile strength (the two latter being about equally large). Finally, strength drops off all the more sharply, the more rapidly a load is applied. One obtains the smallest values for shock-type stresses. As is well known, the naturally deposited snow cover has a distinctly stratified structure, so that each stratum has a different strength value.

2.2 Avalanche Snow

The motion of a flowing avalanche -- a predominantly flowing motion on the ground, in which the individual snow particles remain in contact with one another -- is decisively influenced by the frictional forces occurring between the ground and the moving snow. If the velocity of the snow is v, then for a turbulent form of motion the effective frictional force W per unit length may be formulated as follows [3], [4]:

$$W = \mu N + \frac{\gamma}{k^2} U v^2. \qquad (2)$$

Thus there is a first component which is independent of the velocity and proportional to the force N which acts perpendicular to the surface of deposit. The proportionality factor μ is the coefficient of friction. The second component increases as the square of the velocity and is in addition dependent upon the specific weight of the moving snow γ, upon a coefficient k^2 (often also denoted ξ) which primarily characterizes the roughness of the underlying ground, and finally is dependent upon U which is the contact length between snow and underlying ground measured in cross section. A direct measurement of these factors is not immediately possible; hence they have been in part computed backwards from observed avalanches. For the coefficient of friction today, one assumes values from 0.15 to 0.5 depending upon the nature of the snow and the underlying ground conditions. For the roughness coefficient, one assumes a value of 400 to 600 ms^{-2}. The mean specific weight of a flowing avalanche is estimated to amount to as much as 300 kp m^{-3}.[1]

In the case of powder avalanches -- predominantly a motion of particles suspended in the air -- the velocity-independent component in (2) can be omitted and hence the resistance at the avalanche front becomes substantially dominant. For this type of avalanche, the avalanche snow, in the form of an aerosol, displays very small mean density values. They probably lie somewhere in the range from 2 to 30 kp m^{-3}.

3. Avalanche Dynamics

To the extent that it is important in the structural control of avalanches, some additional remarks should be introduced into this section on the subject of avalanche dynamics. The destructive effect of avalanches is a consequence of their force effects. The latter, if one disregards short-term shock effects, are essentially dependent upon the product of the specific weight and the square of the velocity. In this connection, it is also an important question whether, or under what circumstances, a specific location can be reached at all by avalanches -- which leads to the problem of the run-out distances of avalanches. This distance, over which the originally present kinetic energy is completely consumed, is sharply dependent upon the square of the velocity and upon the coefficient of friction but, on the other hand, only slightly dependent upon the total mass of the descending avalanche. Hence, the velocity appears to be the most important factor in judging the effects of avalanches. On the one hand, this velocity is determined by the material properties occurring in relation (2), and on the other hand, by the local terrain and snow conditions. If a snow stratum breaks off, it then accelerates thanks to its own effective dead weight. But at the same time, the frictional forces become effective in accordance with equation (2). The acceleration continues until the driving force and the braking force are equal; from this moment on, the velocity can no longer increase. The acceleration phase is relatively short. Ninety percent of the constant terminal velocity has been attained in a path length of about 40 times the flow height. But with loose-snow avalanches, this period lasts substantially longer since the flow heights and hence the driving forces at the outset are very small and diminish only slowly. In general, it may be said that the terminal velocities are greater, the greater the slope inclinations and the magnitude of the broken-off snow stratum (or the flow height).

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[1] kp = kilopond force: 9.806 kp = 1 newton. The magnitude of kp measurements is the same as for kilograms.

In certain cases, the size of the fracture area can influence the velocities, too. It is without influence -- this must be repeatedly emphasized -- on even, open slopes where there is no channeling by gulleys. Hence, in the case represented in Figure 1a, the avalanche velocity in the cross section b-b (terminal velocity) remains independent of whether or not the entire region above b-b breaks loose or only that lying above a-a. Also, the run-out distance s remains substantially the same. On the other hand, if channeling exists, then the shape of the starting zone is significant. In Figures 1b and 1c, there are shown schematically two cases which must be differently evaluated. The quantity which is decisive for the velocities is the mean quantity of snow Q_m descending in unit time, for example, in the cross section a-a. It can be estimated by

$$Q_m = \frac{K}{\Delta t} \qquad (3)$$

where K is the volume of the snow masses released and Δt is the time which the snow most distant from a-a required to arrive there; in other words

$$\Delta t = \frac{\ell}{v_m} \qquad (4)$$

Here ℓ denotes the distance covered and v_m the associated mean velocity. If one assumes that in both cases the slope of the terrain and the magnitude of the released snow layer are the same, then it is immediately clear that the case in Figure 1c, owing to the greater volume, gives a higher value of Q_m and hence a higher velocity in section b-b. If in Figure 1c only the right portion of the surface breaks loose, then the volume is only about half as great and the velocities will diminish correspondingly.

These ideas, which have been but briefly sketched, are of some significance in drawing up avalanche risk maps and in planning structural control of avalanches, and they give some leads for evaluating the protective effect which may be expected. In the following sections, this topic will be considered further.

4. Principles of Supporting Structures

4.1 The Problem and the Mode of Action

In the guidelines [2] which have already been mentioned, the task of supporting structures is defined as follows in Article 4.1: "It is the task of supporting structures to prevent avalanches or at least to limit snow motions -- they cannot be completely restrained -- to a harmless magnitude. Fully developed forces as a rule cannot be sustained by supporting structure installations."

Thus, the problem is a double one: the main problem is to produce an overall increase in the stability of the sloping snow cover -- understanding here by stability the ratio of strength to the existing stresses. The secondary problem consists in limiting the size of the snow masses which have been set in motion and in retarding and catching them.

How then can a higher stability be attained in the sloping snow cover? The existing stresses arise in the case which we are considering exclusively from the dead weight. On a smooth slope, this is transmitted from layer to layer by normal and shear stresses to the ground. Under more complicated topographical conditions, a part of the weight is also carried off parallel to the slope and reacts to anchorages such as rocks, trees, or flatter places. In the case of a snowfall on the existing old snow cover, the stresses increase at a rate which corresponds to the intensity of the precipitation. If the stability does not become critical (in other words approach the value 1) the strength must also increase. Experience shows the factors which decide how this development will end, i.e., whether or not there will be a fracture, are usually the shear strengths and shear stresses which arise parallel to a layer. Individual snow strata (snowed-in surface hoar, depth hoar) can often be much weaker in this respect than the preponderant remaining portion of the snow cover. An improvement in stability is brought about here by the normal stresses which by themselves increase the shear strengths and at the same time produce an increase in density (see Section 2.1). If, in spite of this, a shear crack occurs locally, then it will propagate until it reaches a place of higher stability, in other words, a place where the slope inclination is less or where the shear strength is sufficiently high. A slab avalanche produced in this way can therefore attain very great size in the case of a slope whose stable spots are spread widely.

With the installation of rigid support surfaces, conditions in the inclined snow cover are decisively changed. The movements

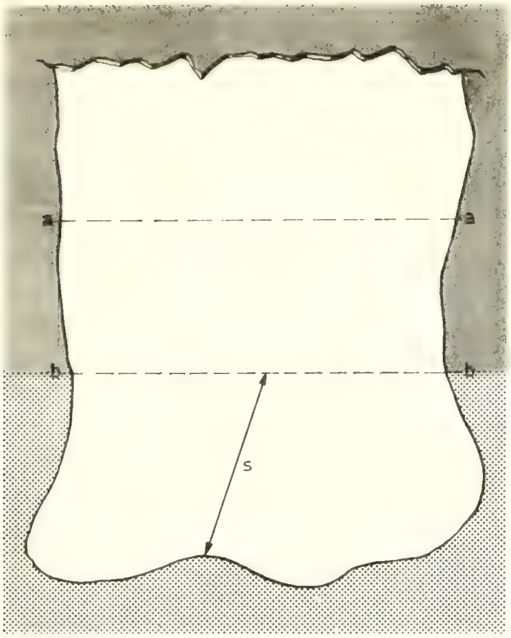

Figure 1a

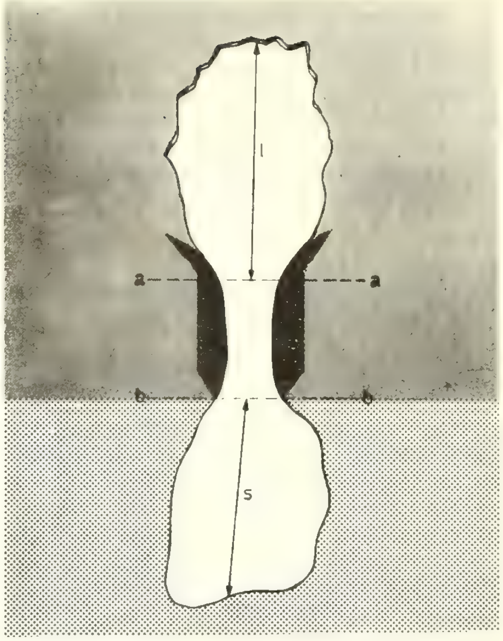

Figure 1b

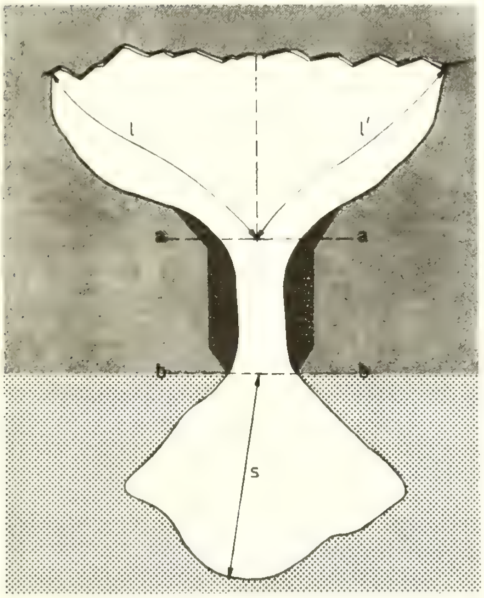

Figure 1c

Figure 1a, b, c, Various forms of starting zones and the track of avalanches.

in the direction of the valley -- ever present, owing to the fluid characteristics of snow described in Section 2.1 -- are held up by these walls with the consequence that in the up-slope direction additional compressive stresses arise over a certain "obstructive region" in accordance with relation (1). These compression stresses absorb part of the dangerous shear stresses (Figure 2). The principal effect of supporting structures therefore consists of a rearrangement of shearing stresses into compressive stresses or under some circumstances also of tensile stresses into compressive stresses. In accordance with Section 2.1, this brings about the desired higher stability: for this type of stressing the strength is substantially greater and the increased densities contribute to a temporally accelerated increase in the strength. If nevertheless, a local fracture takes place, then the propagation of the fracture process is limited by the rows of installations lying above and below, thus there is a limitation also of the size of the snow mass in motion. In such cases, the retarding and catching capability of the support installations also comes into play. The retarding capability is based upon the motion-limiting forces which arise from the rebound. In relation (2), this state of affairs manifests itself in that it is necessary to add a third component which is dependent upon the square of the velocity. It should also be noted that the unpleasant snow motions within the controlled area arise principally as a result of loose-snow fractures. These are not a consequence of the above-described stress phenomena and therefore cannot be prevented by the type of stability increase which has been mentioned. Rather, they are formed in a very small space as a result of the occurrence of instability in small snow particles. Thus, a supporting structure can be effective here only by its retarding and catching capability. In the following section, it is shown that the greatest degree of attention should be given to this aspect of the matter in arranging the installations.

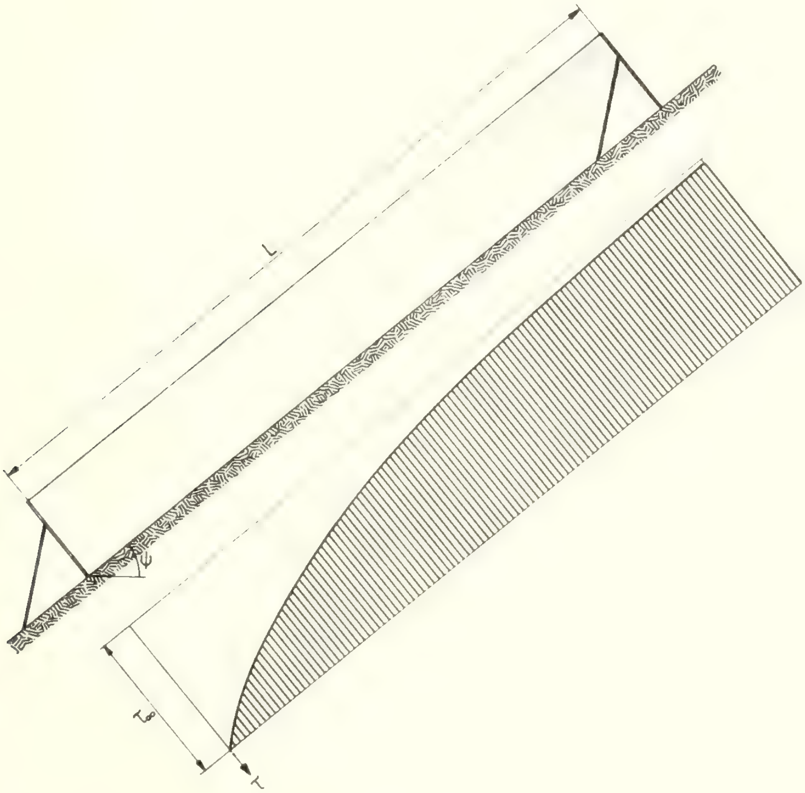

Figure 2. Mode of action of a supporting structure, with the shear stresses acting on the surface of the ground; τ_∞ is the shear stress which is reacted by the ground on a, uniformly inclined slope, with no structures.

4.2 Arrangement and Design

The arrangement and design of supporting structures must be inferred from the assigned tasks of these installations and from their mode of action. The problem is to express the described relationships and requirement in numerical values which can serve as a foundation for a planner. This is a multiform problem. In addition to the already described effects of the material properties of snow and of the topography, there are also those of a generally climatic nature such as precipitation, wind, radiation, and temperature conditions. Further, there are such very important factors as the nature of the ground surface (including vegetation) and the foundational properties of the ground. A further complication here is the fact that in part, scientific investigations which might have served as a basis are lacking and they must be replaced by accumulated experience. But in addition, the planner must consider a feature which has thus far not been mentioned, namely the cost of such a construction. In general, this is very high and hence one is compelled to adapt structural avalanche control to the demands of the objects to be protected or to the acceptable risk. In other words, high cost should not be avoided if the value of the area to be protected justifies it. Half measures would in such a case be the worst possible course and in addition would detract from the reputation of supporting structures. However, for the ratio of cost to reliability obtained there is also an upper limit which it would be wise not to exceed. Figure 3 shows schematically how the cost increases ever more sharply with higher reliabilities. The precise form of the curve depends, among other things, upon the terrain and snow conditions. Two possibilities are represented by a solid line and by a dotted line. With the solid curve, a cost increase of ΔK_1 produces a much higher reliability increase [or "safety increase"] than one of ΔK_2. In the case represented by the dotted line, the relationships are somewhat different, but there too, the curve flattens out considerably for high safety values. Hence, the optimum of an arrangement or of a design is obtained whenever an adequate safety is formulated in such a way that the sharply increasing portion of the cost-reliability curve is fully utilized without at the same time moving into the slightly inclined and therefore uneconomic range. In what follows we shall discuss three features of arrangement and design of supporting structures; these are features which quite substantially influence safety, namely the extent of a supporting structure, the heights of the structure, and the spacing of the structures along the fall-line [line of steepest gradient].

In the "Guidelines," 30° to 50° are given as the inclination range which justifies structures, but here the possibility must not be excluded that in exceptional cases it will be necessary to exceed these limits. As to where the upper boundary of a construction area should lie, there is usually no problem; it should be placed immediately below the highest avalanche starting points. More discussion is provoked by the lower boundary. Since, according to the preceding section, it is the primary shear crack which predominates in the fracture and since this can propagate over very great areas, it is not sufficient to place structures only in the upper parts of a slope. Further, it has been shown in Section 3 how in many cases (e.g., that shown in Figure 1a) the destructive effect of avalanches is practically independent of the size of the fracture area. For example, if one were to halve the cost by putting structures in only half of the fracture area, one would be far from gaining a corresponding increase in safety. In Figure 3, this would correspond to the dotted profile among the shown curves. Hence, structures should extend toward the valley far enough for the terrain inclination to diminish definitively below about 30°. Deviations from this should be considered to be exceptional cases and require precise clarification.

With regard to the height of the structures, there is a fundamental requirement upon which both the degree of avalanche safety in catastrophic situations and also the process of designing the supporting structures rest. This requirement is: structure height must correspond at least to the extreme snow depth to be expected at the site of the structure. By "extreme snow depth" we understand the highest value of the maximum snow depth during a long series of years. If this requirement is not fulfilled, then supporting structures can fulfill their task only partially or not at all. If structures are covered with snow, then at the upper edges of the structure there arises additional shear stresses which are known to promote the formation of avalanches. The retarding and catching capability is then completely lost. In order to have any chance of fulfilling this requirement, one must assume a detailed knowledge of the snow depth distribution over the project area. A merely general knowledge does not suffice, because the snow depths are also subject to sharp variations in small areas. For an adequate determination, one must have about 25 to 100 samples or depth readings per hectare. If possible, the measurements should be carried out during several winters. How extreme snow depths can be inferred from measured depths is explained in the "Guidelines." Here it is important to know that the result obtained will be all the more reliable the closer the measured values are to the extreme values.

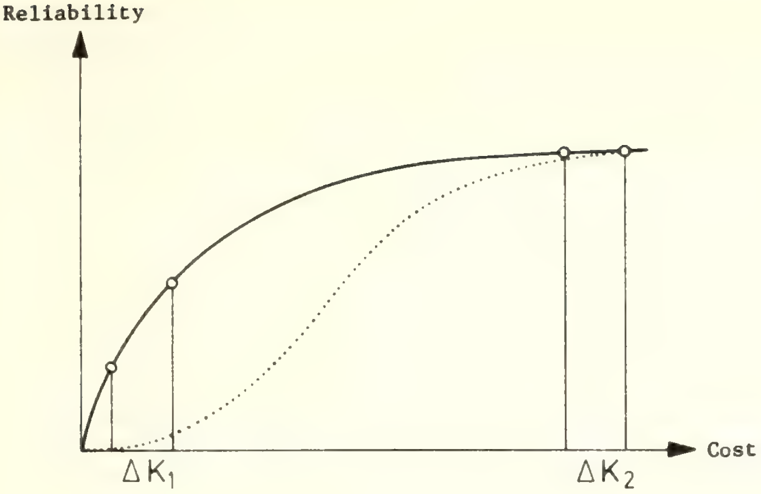

Figure 3. Schematic representation of the relationship of the relationship between cost and the resulting reliability of supporting structures.

The determination of the height of a structure, denoted H_K, at the same time largely determines its dimensions. As has been shown in Section 41, the main task which this dimensioning must fulfill is that of arresting the slow movements of the snow cover in the direction of the valley. The forces resulting in this process determine the dimensions and hence are considered to be the decisive factor. All other stresses, e.g., the dynamic ones, may therefore not be any greater -- which is something that can be achieved by a suitable arrangement. The slope-parallel snow-pressure component S'N (which is the most important factor) in the region which is free of boundary effects amounts to

$$S'_N = \gamma \frac{H_K^2}{2} K N . \qquad (5)$$

per length unit of support surface. Here γ denotes the mean specific weight of the snow cover, K the creep factor which is dependent upon the nature of the snow and the inclination of the slope, and N is the glide factor which is influenced by ground roughness and slope exposure. The values of K lie between 0.7 and 1.05 and N can vary from 1.2 to 3.2. This latter factor takes into account in principle the increase in snow pressure which results from the gliding motion of the snow cover upon the ground surface.

Structure spacings in the fall-line [line of steepest gradient] must be so designed that three conditions are simultaneously fulfilled:

a. The structures must be undamaged by the maximum snow pressure acting statically.

b. In the same way, it must be possible to react without damage to those dynamic stresses elicited by movements of the snow.

c. The velocity of snow movements inside the control area may not exceed a certain limiting value. Thereby the energy of motion which is decisive for damage action is reduced to a harmless magnitude.

If these relationships are presented as a function of the spacing factor -- defined as the ratio of structure spacing to structure height -- and of the slope inclination, then one obtains the three families of curves which correspond to the above conditions and which are shown in Figure 4. For a specific case, one then employs that condition or curve which gives the smallest spacing.

For calculating the family of curves arising from the first condition, the unfavorable assumption was made that the snow lying between two rows of structures has lost its cohesive bonding to the ground and at the same time has slid away, in the form of a rigid slab, somewhat in the direction of the lower structure. The friction forces which in this process relieve the installation of load are looked upon as being velocity independent and are taken into account by the three friction coefficients 0.50, 0.55, and 0.60 given in Figure 4. The curves were obtained by equating the "slab pressure" -- it contains the structure spacing -- resulting from the slippage of the rigid slab, to the snow pressure given by equation (5). Of the three curves, it is the middle one which is taken as the normal curve;

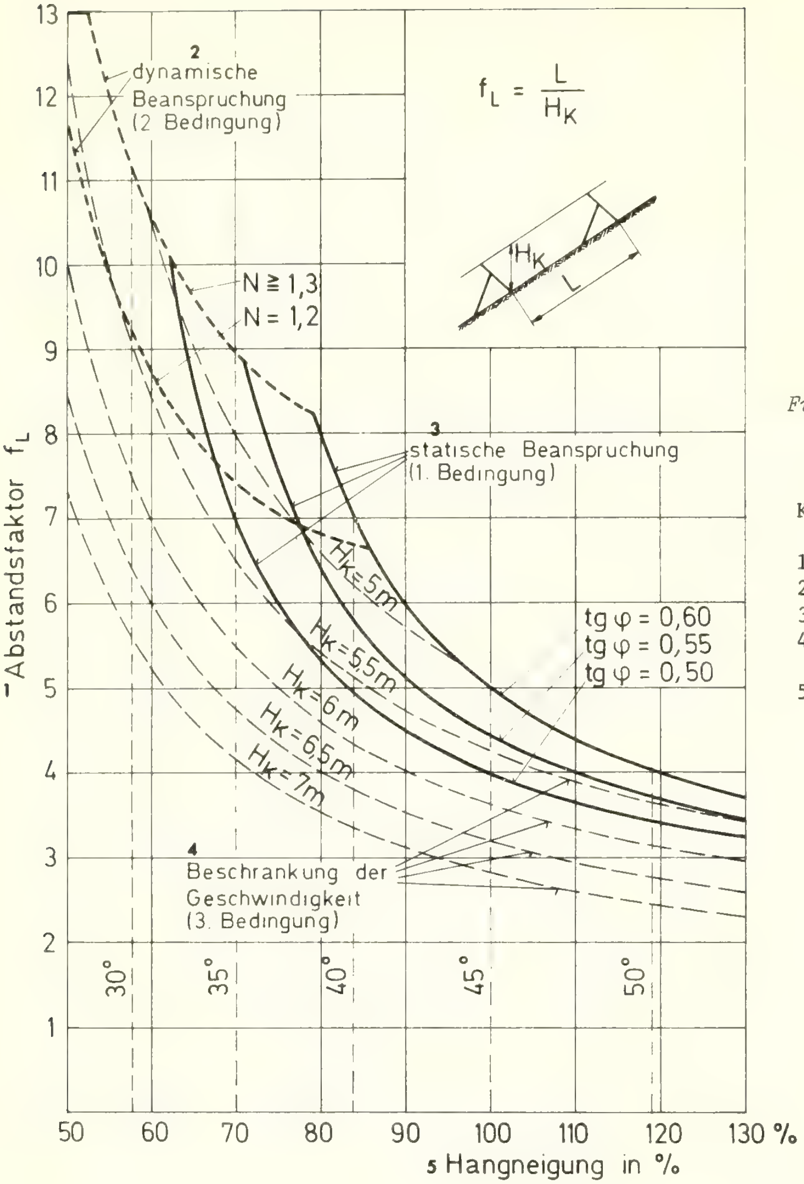

Figure 4. Determination of spacings of structures in the fall-line L.

Key:

1. Spacing factor
2. Dynamic stress (second condition)
3. Static stress (first condition)
4. Restriction of the velocity (third condition)
5. Slope inclination in percent

however, with smooth ground having high glide factors or also in the case of high safety requirements, it is the lower curve with tg $\varphi = \mu = 0.50$ which should be used. This statement is to be interpreted as meaning that this lower curve should be used, for example, also in the case of rough ground and high safety requirements.

On the other hand, the upper curve may be used only for rough ground and simultaneously low safety requirements.

The second and third conditions have to do with dynamic stresses or with velocities. Hence, a relation must be sought which displays as a function of structure spacing the degree to which supporting structures are capable of reducing the velocities. For this purpose, there has been introduced into equation (2) a third term which is proportional to the square of the velocity and which represents the retarding effect and on the other hand also represents the dynamic stress.

The initial slab thickness -- which according to Section 3 has an essential effect upon the velocity -- has been assumed to be proportional to the extreme snow depth. The proportionality factor has been at the same time assumed to be still greater in the case of small slope inclinations than in the case of large inclinations (0.25 and 0.20, respectively), with an increase in shear strength, accompanying increased load, being included in the calculation. If then an overstressing of the structures by snow slides is to be avoided, then the latter must produce forces which are no greater than the snow pressure in equation (5). The equating of both quantities then leads to the curves which correspond to the second condition. Substitution of a constant velocity magnitude (10 ms^{-1}) into the relation between structure spacing and velocity leads finally to the quantitative formulation of the third condition. Attention should now be drawn to the fact that the retarding capacity of the supporting structures depends much upon the deflection angle α, i.e., upon the angle through which a displacement, originally parallel to the slope, is deflected by the obstacle. The smaller this angle, the smaller is the effect. Thus the avalanche structure builder is justified in fearing the so-called revetment formation (shaded part in Figure 5). But it cannot ever be entirely avoided; nevertheless, the situation is most undesirable in which the natural snow cover is deposited in this way, even though the snow depths may be small. The avoidance of grid-beam spacings which are too small prevents such unfavorable depositions of snow. Of course, one must remember that gaps between the beams which are too large also reduce the retarding capacity. Hence, in construction locations where loose snow slides occur very frequently, this group of problems must receive the closest attention.

5. Principles of Deflection and Retarding Structures

5.1 Deflection Structures

By deflection structures, we understand structures designed to oppose avalanche forces and having the purpose of transforming, deflecting, splitting, or preventing lateral extension of a moving avalanche. What is involved here are galleries, terraces, dikes, walls, or wedges. The principles underlying the calculation of such structures follow immediately from the preceding sections. Here it should be noted that in the velocity calculation, it is better to assume small coefficients of friction in order that the decisive extreme conditions will be included. The conventional values lie between 0.15 and a maximum of 0.30. In computing the friction forces operating on the structures, usually only the velocity-independent term is taken account of in relation (2). This is done for the sake of simplicity, but also because normally in making field measurements, it is possible to determine only the ratio of the maximum total normal and shear stresses (mechanical maximum

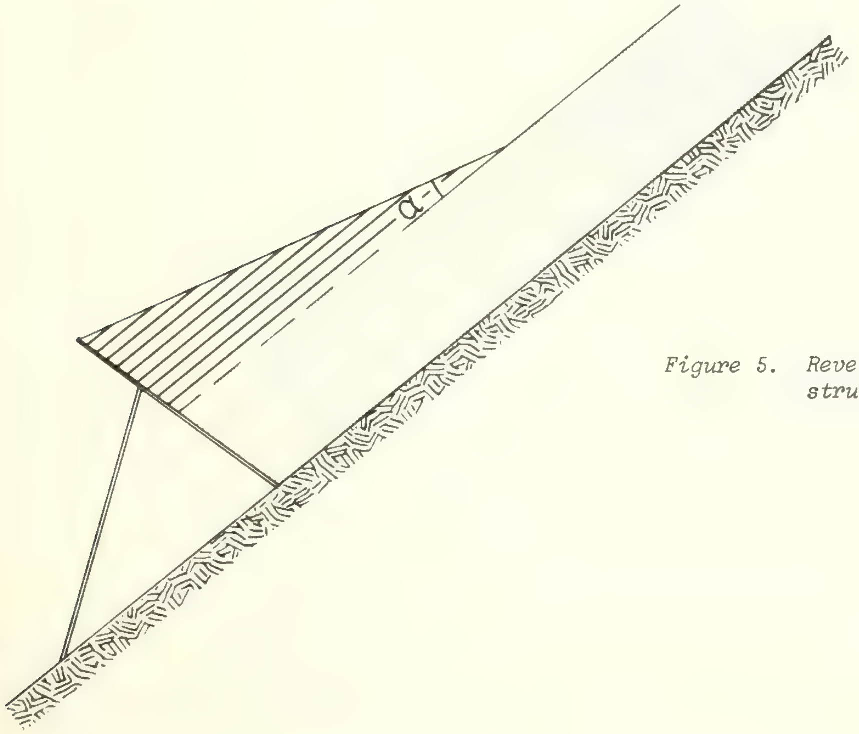

Figure 5. Revetment formation for a supporting structure.

force measurement). Thus, one must be content with a "lump sum" coefficient of friction. Hence, these coefficients must here be set rather high; as a rule, one selects values between 0.30 and 0.50.

A certain degree of care is in order in the case of structures which aim at a lateral change of direction. It is not possible for any arbitrary avalanche to be deflected through any angle, at least if one wants to remain within the range of reasonable dike or wall heights. In general, the rule holds that the possible deflection angle becomes smaller, the more rapidly an avalanche flows. Therefore, in the case of very rapid powder avalanches, such measures have little prospect of success. What is most likely to have success is the case when the natural terrain itself causes a substantial deflection. It is also true that in an extreme case, an artificial strengthening of the terrain can be used to guide the avalanche flow into the desired direction.

5.2 Retarding Structures

Retarding structures are designed to deal with avalanche forces and which are opposed frontally to the avalanche with the object of arresting its mass or of shortening its run-out distance. This involves arresting [catching] dikes, and retarding mounds, wedges, and blocks. As in the case of a lateral deflection, here, too, the principle holds that not every avalanche motion can be slowed in any location and arrested, but rather the natural terrain must be of such a nature that in the normal situation an avalanche comes to a halt there. Then measures which artificially strengthen the terrain produce an arrest of the extreme avalanche also.

The retarding of an avalanche by means of artificial measures is based primarily upon the two following effects:

The obstacles, by being arranged in such a way as to be mutually displaced relative to the flow direction produce a lateral distribution of the avalanche flow so that compared to the undisturbed state, a substantially greater flow breadth is attained. Because of this magnification, however, the flow height and hence also the velocity must diminish. From this it follows that the obstacles should be so arranged to produce as uniform a distribution as possible of the avalanche flow over the available terrain. In addition, the obstacles must also be sufficiently high, relative to the expected flow heights. Further, the terrain should display a certain minimum breadth transversely to the avalanche direction if there is to be any effectual broadening at all. Therefore, narrow, deeply cut gullies are not suitable for retarding structures.

The subsequent mode of action in retarding is immediately evident from relation (2). The second term in this relation is dependent upon U which is the contact length between snow and underlying ground, this length being measured in a transverse section perpendicular to the motion of the avalanche. This length is magnified by the installation of artificial obstacles. But in addition, there also come into operation (see Section 4.2) the rebound forces which are responsible for the retarding capacity of supporting structures. From what has been said, it may be inferred that artificial obstacles are all the more effective the more they elongate the transverse cross section line of the ground surface relative to the original state and also the greater the area which these artificial obstacles oppose to the avalanche. Hence, the most effective procedures should be the retarding mounds made of earth. To arrest an avalanche means to bring it completely to a standstill with the aid of an artificial obstacle (dike or wall). This is accomplished by forcing the avalanche snow to flow upward to such an extent that its kinetic energy is completely dissipated. The decisive quantity here is the so-called energy-line elevation; in hydraulics it is given by the Bernoulli equation and consists of the sum of velocity head, flow head, and height above a reference plane. However, this equation requires adaptation to such a medium as avalanche snow since in contrast to something like water, internal friction forces are activated during deformation [5]. For a rough estimate of the required structure height H_D, this effect, however, should be neglected and one obtains as the condition:

$$H_D \geqq \frac{v^2}{2g} + H_L + H_S \qquad (6)$$

The first term on the right represents the velocity head. v is the velocity immediately in front of the obstruction and g is the gravitational acceleration ($9.81\ \mathrm{ms}^{-2}$). H_L denotes the flow height of the avalanche measured vertically, and H_S represents the maximum depth of naturally deposited snow which in the extreme case exists in front of the structure. From relation (6) it is immediately apparent that an avalanche can be arrested at reasonable cost only if the velocity in front of the obstruction is not too great. But this is in general the case only when the avalanche has previously traveled through a run-out terrain and lost a corresponding amount of energy -- an effect which, if possible at all, should be amplified by artificial means. Hence, the normal case is a combination of retarding structures and arresting construction, with the arresting installation being installed at the lower end of the run-out terrain. A run-out terrain is distinguished from the track in that the slope inclinations of the former are on the average no greater than about 12° to 15°. Further, the length of this terrain must correspond roughly to the run-out distances of normal (i.e., not extreme) avalanches.

6. Concluding Remarks

Within the limits of this work, it has been possible to deal with only a few problems of structural avalanche control. In this choice, the attempt has been made to treat such questions as have perhaps more often than others been an occasion for discussion or whose aspect has been subjected to a marked modification by the progress of research and experience in the past 20 years.

Rigid schemata should definitely be avoided in structural avalanche control. Rather, those who build avalanche control structures, on the basis of his evaluation of the ever-changing conditions on the one hand, and on the basis of the requirements on the other, must reach solutions which are economically balanced in proportion to the values protected.

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[1] Recent Developmental Tendencies and Problems of Avalanche Control Structures in the Starting Zone.

[2] Avalanche Control Structures in the Starting Zone, Guidelines of the Federal Forest Inspectorate for Supporting Structures.

[3] On the Destructive Force of Avalanches.

VI. PERMANENT SUPPORTING STRUCTURES

(Walter Schwarz, Interlaken)

This article does not form a comprehensive and finished account of permanent supporting structures. Rather, in addition to general data, various special problems are treated which confront the avalanche-control builder.

1. General Remarks

A distinction is made between temporary and permanent supporting structures in the starting zone. Temporary supporting structures aim at a provisional stabilization of the snow cover.

This temporary protection can be achieved by

a. permanent supporting structures which are taken out after their protective purpose has been achieved; in this manner, for example, power plant construction sites have been temporarily protected by means of light metal snow bridges, or in the case of other construction sites, with snow nets.

b. temporary supporting structures with a limited lifetime (principally of wood), which support the snow cover provisionally until the growing afforestation can take over this function after on the average 20-40 years.

Up to now, in temporary supporting structures, very often too low a degree of safety has been accepted; in future this should be avoided.

Permanent supporting structures in most cases strive for a high degree of safety and assume a permanent or long-term protective effect. Hence, they must employ durable building materials.

Permanent supporting structures will always be the appropriate choice wherever

a. it is not an individual object which is protected but an area (e.g., protection of a town, protection of several traffic arteries one above the other);

b. the high cost of the supporting structures bears a carefully weighed ratio to the value of the objects protected and where

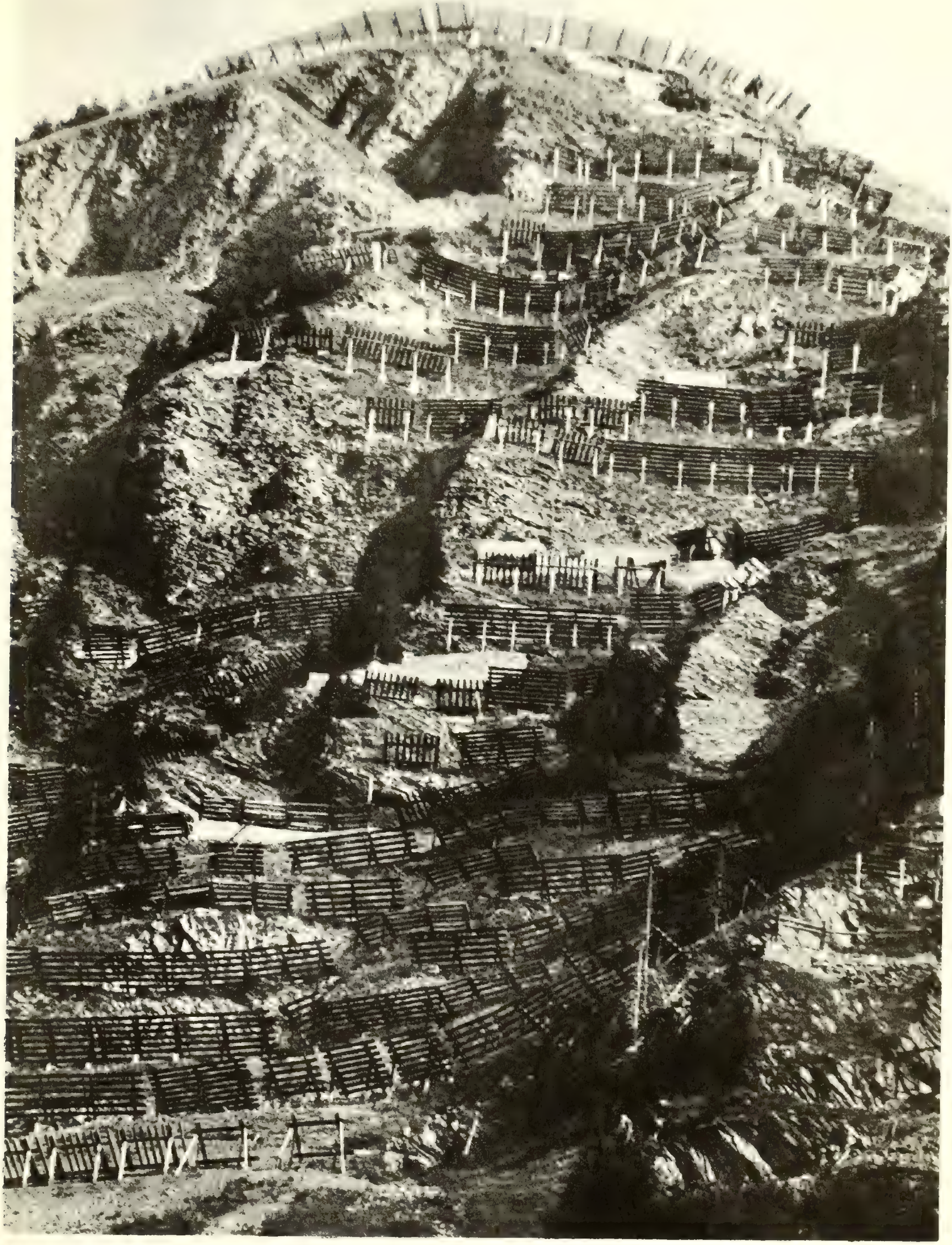
c. overall treatment of an entire region occupies the foreground.

The potentialities of the use of permanent supporting structures and their limitations, as compared with other types of structures, will be shown in the following by means of the example of National Highway N 2 through the Reuss Valley from Amsteg to Goeschenen. This illustrative project is unique in the alpine region both with respect to the great variety of its features and with respect to the concentration of the measures employed. Its various constructive measures protect 5,250 running meters or 37 percent of the 14.2-km-long distance against avalanches. Its individual permanent structural measures are distributed as follows:

Table 1. Nature and Extent of Permanent Avalanche Control Structures Along National Highway N 2 Between Amsteg and Goeschenen

Type of Structure	Protected Distance [m]	Fraction of the Total Construction [%]
Tunnels	1,250	23.8
Avalanche galleries	1,880	35.8
Avalanche guiding structures (lateral)	210	4.0
Avalanche arresting spaces	160	3.0
Retarding structures	50	1.0
Supporting structures combined with afforestation	1,700	32.4
Total	5,250	100.0

Tunnels have been built under numerous deeply channeled avalanche paths; in cases when there is a purely linear protection requirement and when simultaneously the costs of supporting



structures would not be financially tolerable, galleries suggest themselves; avalanche-guiding structures serve for deflection, channeling, or constriction of lateral extension (shortening of the gallery lengths!) of flowing avalanches. In addition, outside the stretch from Amsteg to Goeschenen, N 2 must be protected in the Silenen area against the well-known Wiler avalanche (27 January 1968, seven avalanche dead) and the Opplital avalanche. Against these avalanches from very large and hence uncontrollable starting zones with areas of about 100 and 27 hectares, respectively, the following measures have been provided:

Against flowing avalanches:

Creation of large arresting spaces (can also be combined with lateral guidance structures and retarding structures) by the removal of material amounting to some 100,000 cubic meters, which has been used in the construction of N 2.

Against powder avalanches:

Frontal avalanche guidance dikes having a length of about 800 m and height of 8 m measured from the highway level immediately on the mountain side of the highway route in order to conduct the powder avalanche component over the highway. The effect of these dikes is similar to that of snowdrift walls; the highway is located in the protection range of the dikes. The compression shock of the powder avalanche is absorbed by the dike and the avalanche jumps over the highway.

Supporting structures should be mentioned as the only construction measure which prevents avalanches. This type of structure, in the case of the N 2, accomplishes the following protective tasks:

Steintal/Hustal (Gurtnellen) project:

a. Surface protection of the N 2 and of the Gotthard highway for about 1,000 m against actual and potential avalanches;

b. Simultaneous protection of the settlements of Wiler as well as a group of buildings in Alphorn and Alpenroesli/Kirche.

Entschigtal (Wassen) project:

a. Protection of the SBB [Swiss National Railway] (twice), of the Gotthard highway, and of the N 2;

b. Protection of the southern boundary of the town of Wassen.

Laubzuege (Wattingen) project:

a. Protection of the tunnel portal of the SBB, of the N 2, and of the Gotthard highway;

b. Protection of the arsenal and the settlements of Wattingen.

2. Supporting Structures and Their Protective Effect

The protective effect of a supporting structure in accordance with guidelines [1] depends upon

a. the position of the object to be protected: for example, the same degree of safety cannot be obtained by supporting structures for a railroad running through a steep slope as for a village at the bottom of a mountain valley;

b. the topography of the starting zone: for example, the effectiveness of supporting structures on a steep lee slope is more doubtful than it would be on the windward side of a convex and smooth mountain ridge;

c. the nature, especially, of the new snow masses: thus in the case of very loose snow masses which have fallen at a low temperature, limited snow movements can occur throughout the entire protected area as the result of widespread avalanche fractures;

d. the types of structures employed and the method of construction: a broken arrangement of snow nets having low retarding and arresting capacity will not

Figure 1. Partial view of the permanent supporting structures Wilerhorn/Brienzwiler (1,700-2,004 m above sea level) in sharply eroded terrain invaded by rock falls; snow bridges, snow rakes, and avalanche fences in continuous and broken arrangement, depending upon terrain conditions; supplementation of the articulated supporting structures by massive dry walls, mainly as protection against rock impact; on the left portion of the summit knoll (windward side) snow bridges OeAM having a high degree of filling (65 percent) functioning to reduce the amount of drift snow in the uppermost right-hand portion of the area (lee side); true snow fences OeAM (bright band) behind the above-mentioned snow bridges with a high degree of filling (photo W. Schwarz).

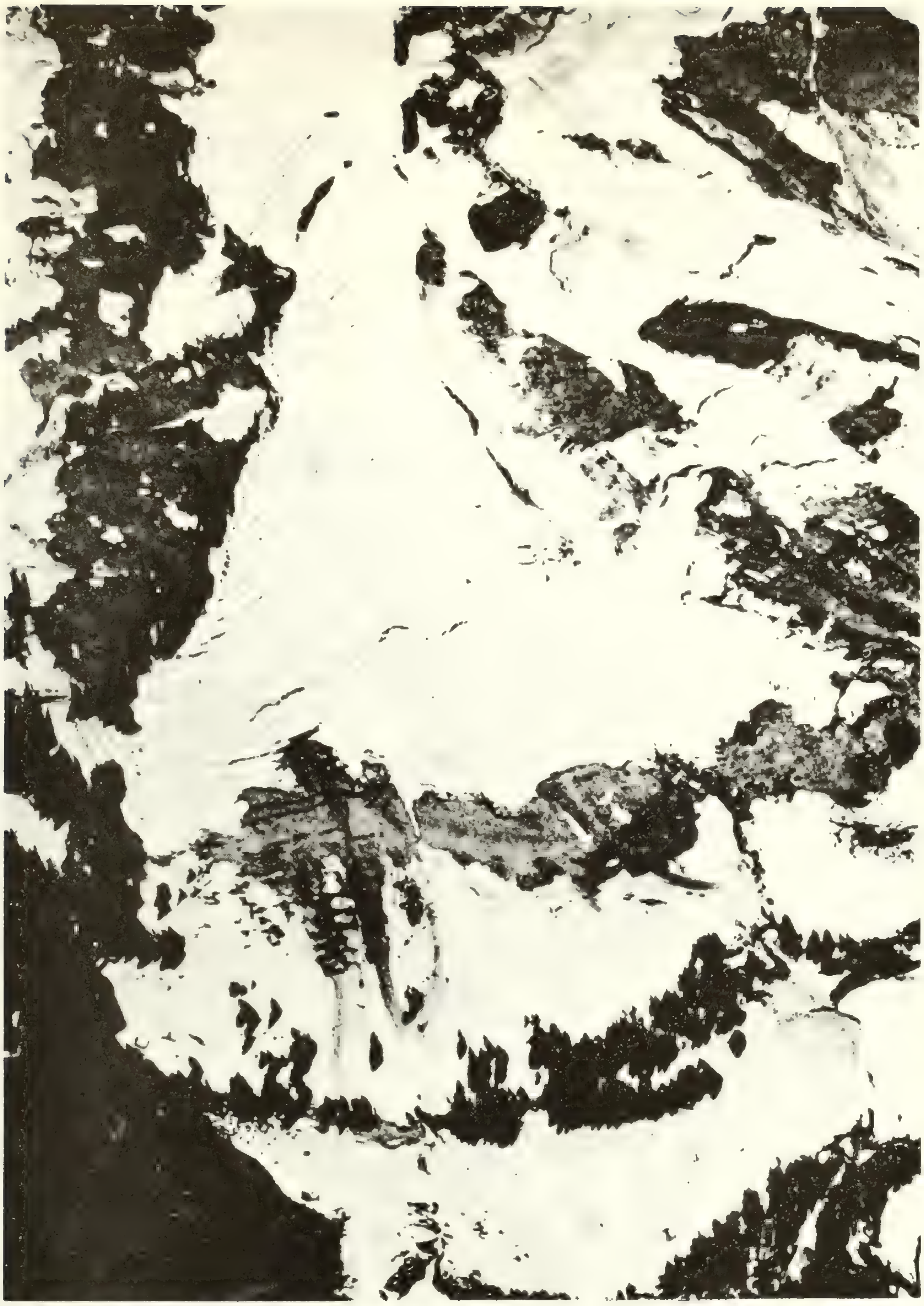


Figure 2. Avalanche structures Tanngrindel/Brienz in the run-out zone [Ausaperungsphase]: the portions of the slope with no structure have discharged their snow masses; the stabilization of the snow cover by means of supporting structures is evident. In the lowest right-hand part of the protected area, glide cracks have been able to form. In later years these could be prevented by the installation of glide-protection bridges OeAM. A snow-drift structure with a length of about 100 m and OeAM walls is located on the summit field of the project (photo W. Schwarz).

be able to meet the same high safety requirements of a continuous arrangement of snow bridges or snow rakes;

e. the position and configuration of the boundary of the protected area: i.e., partial protection of large starting zones can loose a great part of their effectiveness with respect to preventing avalanches if, as a consequence of unwise location of the structure and inadequate boundary protection, avalanches can break into the protected area from other parts of the slope.

From the dependence of the attainable safety upon various factors, it follows that supporting structures cannot provide an almost absolute safety, as is the case with an avalanche gallery, but instead most of the time, additional precautionary measures are to be recommended, such as, for example:

a. The snow deposits near supporting structures should be continuously observed in winter in order to correctly estimate the level of effectiveness of the structures, especially in situations of general avalanche danger and in order to

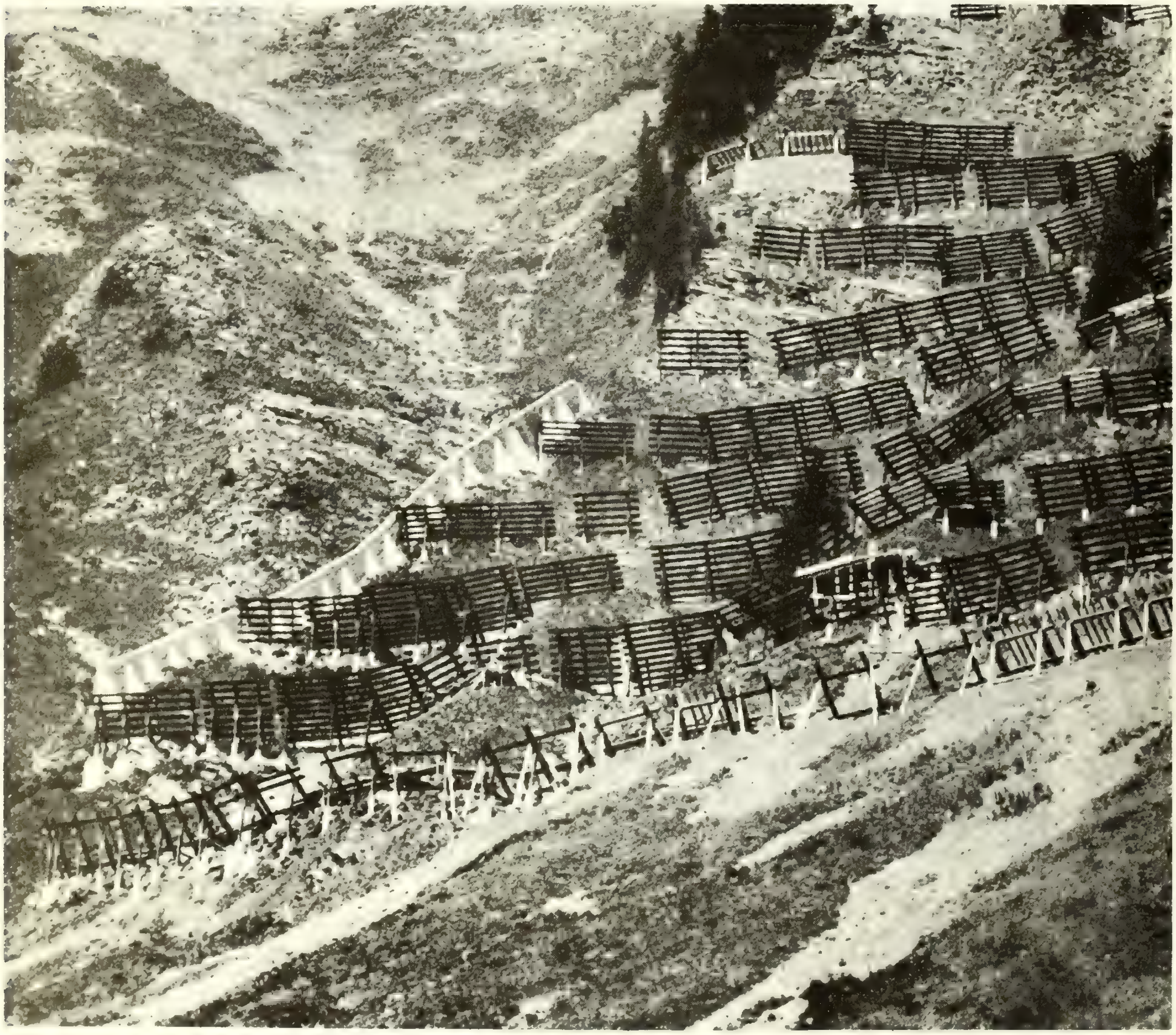


Figure 3. A concrete guiding wall of 2.5-5.0 m height here protects the supporting structures against heavy and frequent avalanches from adjacent unprotected regions (Wilerhorn/ Brienzwiler, photo W. Scharz).

be able to promptly institute possible safety measures (e.g., closure of certain regions).

b. In avalanche zone planning, one may not always count upon complete protective effect from the structures; hence, regions bordering on steep slopes with structures should be classified with the highest degree of caution.

c. In protecting highways and railroads along the base of slopes or through steep slopes, additional arresting spaces should be created as close as possible in front of the object to be protected, for example, by shifting the route in the direction of the valley, erecting true arresting structures in some form (avalanche fences, snow bridges, etc.) and by covering the lowest structures with diagonal weaving.

d. It is always possible to combine structures with afforestations. As the protecting forest grows, the level of safety increases.

The problem of zoning must still be briefly discussed in relation to what has been said above. The main object of avalanche zoning is to prevent further occurrence of new settlements (dwelling houses together with all possible transportation arteries) in avalanche-endangered zones if there is a possibility that

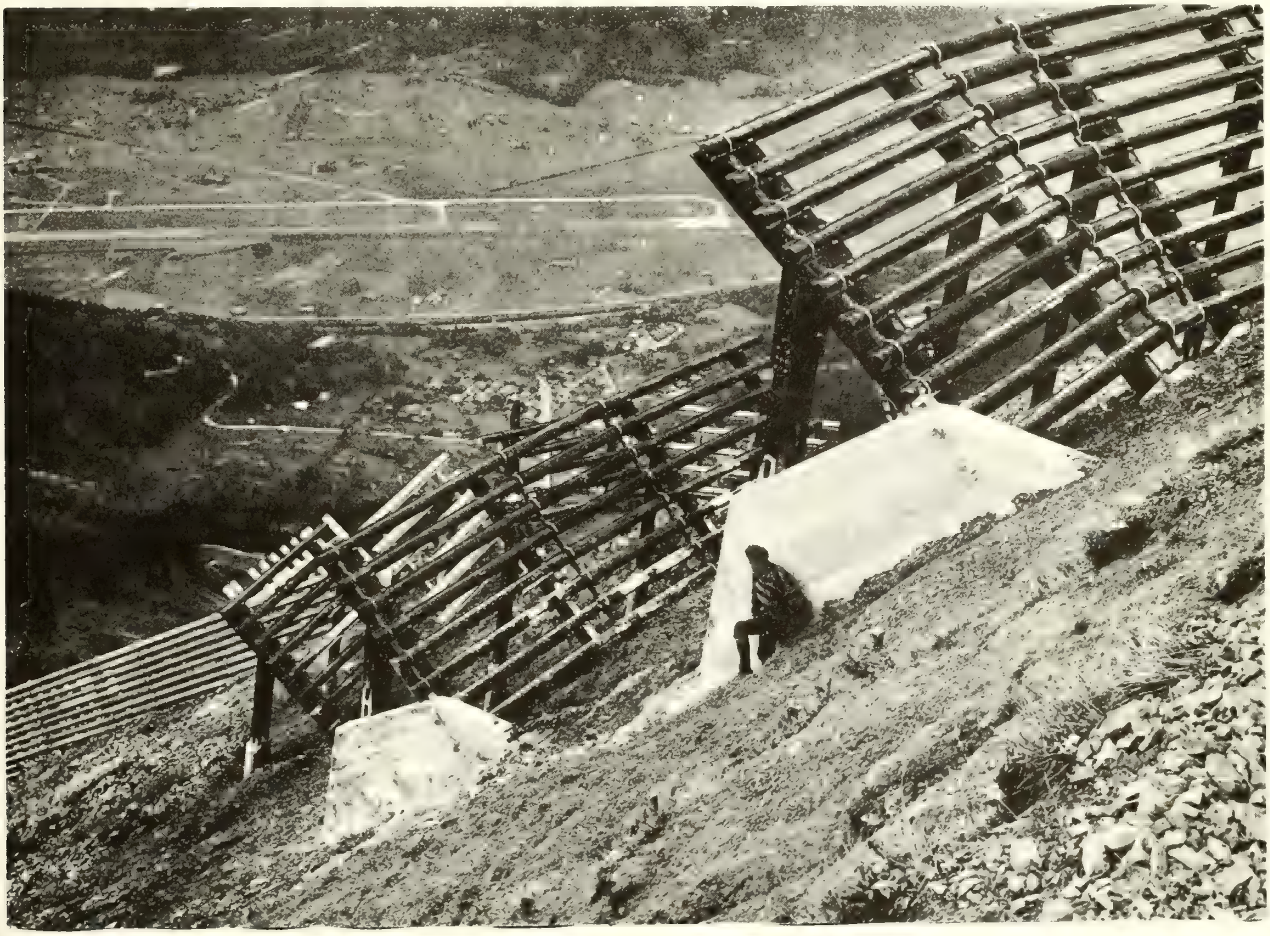


Figure 4.--Additional snow bridges with a minimum length of 10 m and at half the installation spacing (middle) together with a guiding wall of steel OeAM (bottom) keep surface slab avalanches from entering the built-up area from adjacent slopes. The snow bridges OeAM (above, with D_K = 4.0 m and below, with D_K = 3.5 m) are protected against the edge effects by means of double boundary blocks and concrete disks (Wilerhorn/Brienzwiler, photo W. Schwarz).

these might later necessitate new and expensive structural control. In order to gain one square meter of new building land, it is possible for several hundred francs worth of supporting structures to be required. Private means are scarcely available for such operations and the means of the federal government and of the cantons must be predominantly reserved for the protection of existing settlements.

3. Planning Supporting Structures

Before starting to build supporting structures, all other construction and combination possibilities must be checked out (guidance installations, galleries, retarding structures, and arresting structures, direct protection structures, snow-drift structures). In this way, it is often possible to achieve not only a substantial saving of cost, but also to achieve effective protection more rapidly.

The planning of supporting structures must be preceded by as thorough a determination as possible of the avalanche history, climate, topography, geology, and vegetation as well as by a clarification of the transportation possibilities; observations of snow depth distribution and avalanche conditions are especially important.

The designation of the most important construction areas is of decisive importance in large construction regions and can be undertaken only on the basis of the above data. At the same time, one must adhere to the principle that a project should not be limited only to the most important, already observed, or potential starting zones, but also that these areas must be protected as much from above as from the side. Hence, a construction project always begins at the highest starting zone, even if the most important fracture areas lie further down.

Slopes from 30° to 50° are today considered generally to be in the range which justifies construction. Of importance in connection with these limiting inclinations is the determination of the downhill extent of a project. Projects which have been made too small -- whether because of an alleged lack of money or because the danger coming from outside the protected area was wrongly estimated -- necessarily lead to reverses and bring discredit to supporting structures.

Where a lasting protective effect is sought there arises the need to decide whether structures should be temporary or permanent and in particular as to the possibilities for afforestation and their chances of success. Permanent structures, except in treeless regions, should be erected anywhere a natural avalanche protection, in the form of reforestation, requires a longer span of time than the maximum lifetime of temporary supporting structures (compare H. in der Gand, Article 7). This applies especially to the upper tree line and at lower elevations to unfavorable locations. In such zones, supporting structures can be erected with permanent foundations and a temporary grid (e.g., using impregnated wood).

The layout of the structures in the terrain is accomplished in accordance with the "Guidelines for Supporting Structures" [1] (compare B. Salm, Section 4.2). In these guidelines, structure spacing in the fall-line is arranged according to structure heights H_K. Since the effective grid heights D_K in practice amount to 2.0 to 5.0 m with staggering of the structure sizes at 0.5 m intervals spacings based upon H_K are only conditionally suitable for the structure layout. Therefore, in Table 2 for the normal cases, the spacings in the fall-line have been arranged according to the slope inclination and the effective grid height.

In setting up the provisional cost estimates, the number of running meters of supporting structure represents the most important cost factor. For small areas it is best to use the layout in the terrain to determine the required number of running meters of supporting structures. For large areas, this method is not usable; instead one must resort to a computational method which helps avoid erroneous evaluations and thus bad cost estimates.

The number of running meters may be reliably estimated by the following formula:

$$LZ = \frac{F}{f_L \; D_K} \alpha \; [m'] \qquad (1)$$

Here: LZ = number of running meters
F = construction area in m^2
f_L = spacing factor according to guidelines
D_K = effective grid height (2.5/3.0/3.5/4.0/4.5/5.0 m)
α = gap factor of the structural arrangement, which assumes the following values:

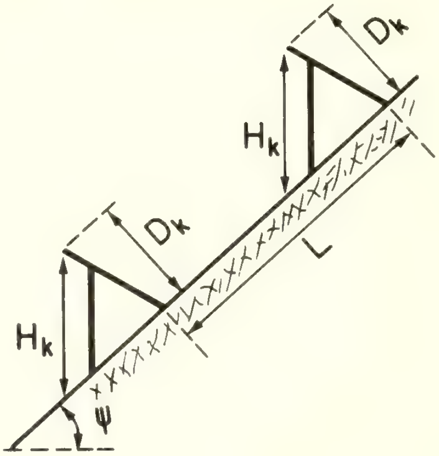
Gap	Gap Factor
4-2-4-2-4 m	0.68
10-2-10-2-10 m	0.84
22-2-22-2-22 m	0.92
Continuous	1.00

The numbers 4/10/22 m denote the structure lengths and 2 m denotes the gap between structures in the same line.

Table 2. Structure Spacings [L] Down the Fall-Line According to D_K (for notation see text)

ψ [°]	D_K [m]	H_K [m]	L [m]	ψ [°]	D_K [m]	H_K [m]	L [m]
30	2,0	2,31	25,6	45	2,0	2,83	12,6
	2,5	2,88	32,0		2,5	3,54	15,8
	3,0	3,46	38,4		3,0	4,24	18,9
	3,5	4,04	44,8		3,5	4,95	22,0
	4,0	4,62	51,3		4,0	5,66	22,9
	4,5	5,20	50,1		4,5	6,36	21,3
	5,0	5,77	47,9		5,0	7,07	19,8
35	2,0	2,45	21,9	50	2,0	3,11	11,7
	2,5	3,05	27,1		2,5	3,89	14,6
	3,0	3,66	32,6		3,0	4,67	17,5
	3,5	4,27	38,0		3,5	5,44	20,4
	4,0	4,88	40,0		4,0	6,22	18,7
	4,5	5,49	35,7		4,5	7,00	17,2
	5,0	6,11	33,6		5,0	7,78	15,6
40	2,0	2,61	15,1				
	2,5	3,26	18,9				
	3,0	3,92	22,7				
	3,5	4,57	26,5				
	4,0	5,22	30,3				
	4,5	5,87	26,4				
	5,0	6,53	24,8				

Note: Structure spacings have been derived using spacing factors f_L for a gliding factor, $N \geqq 1.3$ and a coefficient of friction for snow on ground of $\operatorname{tg}\psi = 0,55$



Illustrative calculation

To use formula (1), it is necessary first to determine the construction area (74,000 m^2), the average slope ψ (40°) of the area, and an estimate of the average extreme snow depth $\bar{H}_{ext}$ (350 cm). In this way, the spacing factor f_L (5.8 according to the mean guidance curve $\operatorname{tg}\psi$ 0,55) can be derived. By means of the average extreme snow depth and average slope, one computes the associated snow cover thickness [⊥ to slope] [maechtigkeit] ($D = \bar{H}_{ext} \cos\psi = 350 \cdot 0.766 =$ 268 cm) and then one selects the corresponding, next largest installation size setting $D_K =$ 3.00 m.

From this one gets:

$$LZ = \frac{74\,000}{5{,}8 \cdot 3{,}00}\, z = 4253\, z$$

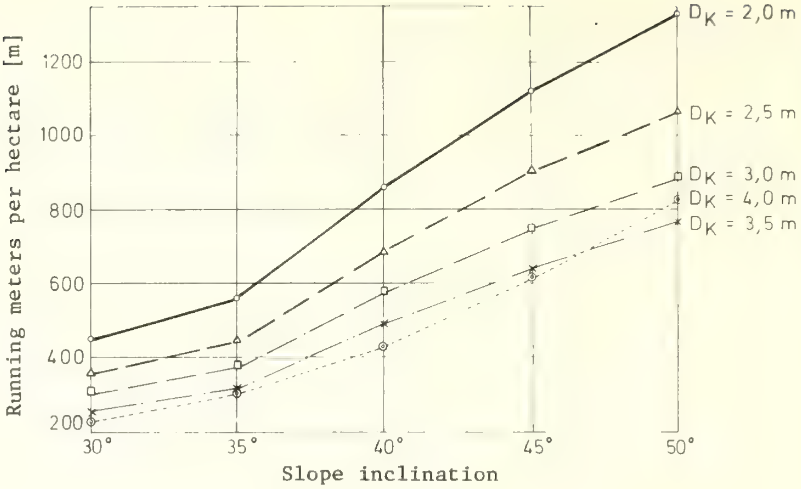
The choice of the gap factor is left to the planner:

For continuous arrangement with α = 1.00 we have LZ = 4,253 m, for broken arrangement 4-2-4-2-4 m with α = 0.68 we have LZ = 2,892 m.

The families of curves of running meters per hectare for the most conventional D_K are plotted in Figure 5 for continuous arrangement. These running meter figures can be multiplied by the appropriate gap factor α to get the desired value for broken arrangement.

No attempt is made to present the running meter figures per hectare for structures having a D_K of 4.5 and 5 m since such structures occur only as individual structures and never for entire projects. Already in the uppermost range of the curve for 4-m installations it is evident that the rule of thumb "the taller the structure the bigger the structure spacing and the smaller the running meter figure per hectare" is no longer valid for the greatest H_K. Thus, the curves for structures having D_K = 4.5 and 5.0 m run substantially above the curve D_K = 4 m -

Figure 5. Running meters of supporting structures per hectare for continuous arrangement, $N \geqq 1.3$ and tg φ 0,55.



which is related to the assumed fracture heights of unavoidable snow movements and to the design velocity limitation (compare B Salm, Section 4.2).

With the gap factor α of a project, it is also possible to directly derive the reduction in the number of running meters for broken arrangement as opposed to continuous arrangement ($\alpha = 1.00$). This reduction amounts to 32 percent for broken construction having alternately 4 m of installation and 2 m of gap and for 10/2 m it amounts to 16 percent and for 22/2 m it amounts to 8 percent.

Since the costs per meter of intermediate tie-piece fittings for bridging the gap between structures amounts to only about 60 percent of the cost of the structures themselves, there is no significant savings from leaving gaps. In addition, the installation of intermediate tie-piece fittings is associated with no additional foundation costs. It is therefore not logical economically to strive for as large a gap as possible in the line of structures when, at the same time, one perhaps obtains a significant reduction in the degree of safety.

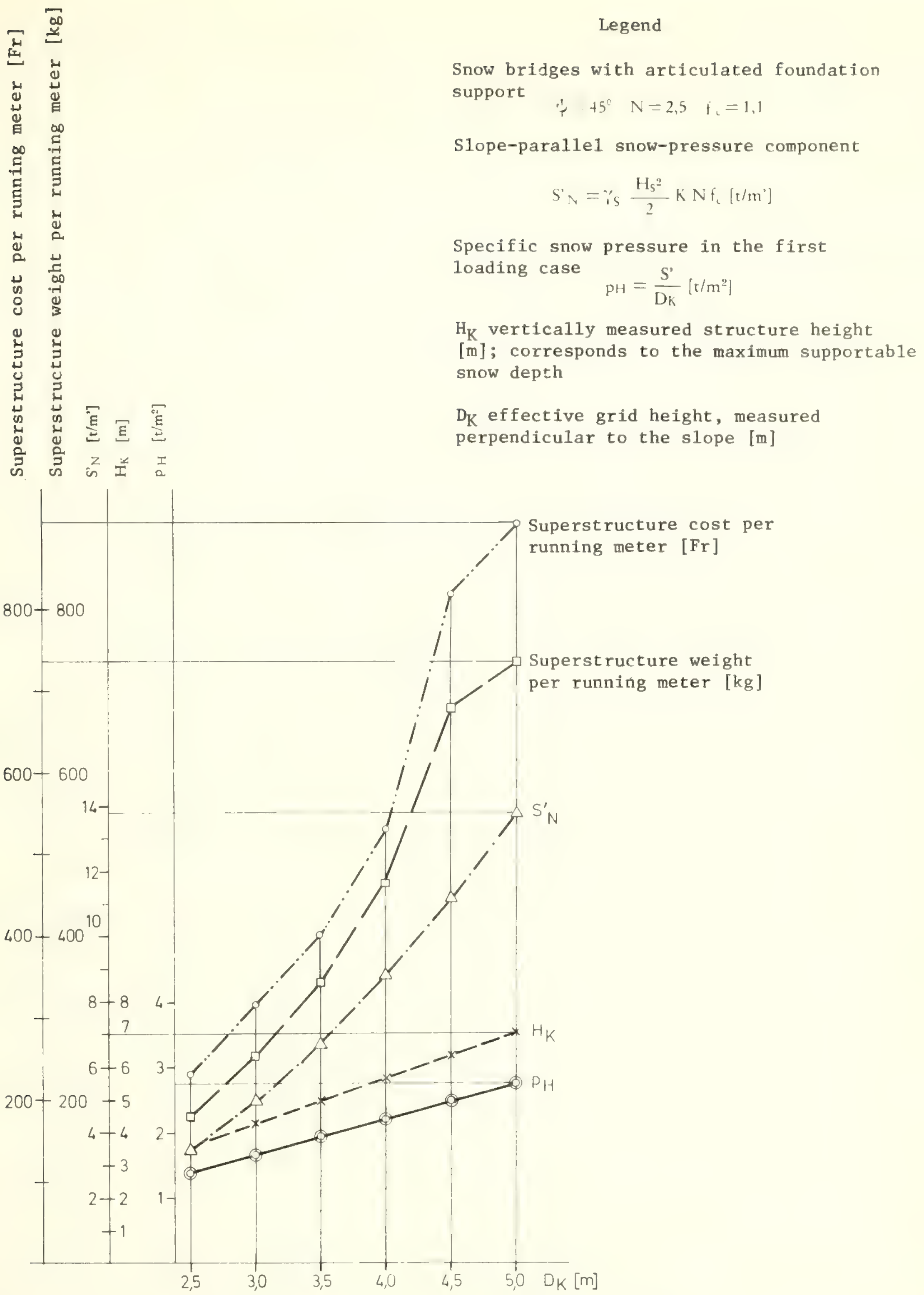
More important than the question of gaps is constructing the entire project in accordance with the guidelines. If one investigates the number of running meters per hectare of supporting structures for existing projects, one discovers surprisingly small values in some cases.

4. Running Meter Costs as a Function of the Grid Height D_K

At the present time, for completely installed steel snow bridges (slope inclination $\phi = 45^o$, glide factor N = 2.5, height factor $f_c = 1.1$, structure lengths of 22 m) one must figure on prices up to 850 francs per running meter for structures having $D_K = 3.0$ m and 1,400 francs per running meter for structures having $D_K = 4.0$ m.

Since above prices depend sharply upon transportation costs which vary from project to project and therefore upon the required volumes of concrete (0.15 m^3 up to 1 m^3 per foundation), for the following analyses just the costs for the superstructure, which are substantially fixed, are included. The costs and weights of the superstructure, per running meter, in Figure 6 are understood to be for steel snow bridges of the Austrian-Alpine Montan Company (OeAM) having normal design pin-jointed foundation bearings and with delivery costs prepaid. Figure 6 shows the marked dependence of the running meter prices upon the effective grid height and the steep rise in these prices for structures having a high D_K.

The purchase of a steel snow bridge with $D_K = 5.0$ m is 75 percent more expensive than one having $D_K = 4.0$ m; in addition, on a hectare at a slope inclination of 45^o and using the continuous form of construction, the corresponding snow depths require 700 running meters of support installation with $D_K = 5.0$ m in contrast to 600 running meters with installations having $D_K = 4.0$ m. Thus, the largest installation types should be employed with some restraint and it is preferable to be on the lookout for possibilities of snow depth reduction by means of snow-drift structures or, for example, one might put supporting structures of $D_K = 4.0$ m on walls in order to gain height.



Legend

Snow bridges with articulated foundation support
$\psi \quad 45^\circ \quad N = 2{,}5 \quad f_c = 1{,}1$

Slope-parallel snow-pressure component

$$S'_N = \gamma_S \frac{H_S^2}{2} K N f_c \; [t/m']$$

Specific snow pressure in the first loading case
$$p_H = \frac{S'}{D_K} \; [t/m^2]$$

H_K vertically measured structure height [m]; corresponds to the maximum supportable snow depth

D_K effective grid height, measured perpendicular to the slope [m]

Superstructure cost per running meter [Fr]
Superstructure weight per running meter [kg]
S'N [t/m']
HK [m]
pH [t/m²]
800
800
600
600
400
400
200
200
14
12
10
8
8
7
6
6
5
4
4
3
2
2
1
4
3
2
1
2,5
3,0
3,5
4,0
4,5
5,0
DK [m]
Superstructure cost per running meter [Fr]
Superstructure weight per running meter [kg]
S'N
HK
pH

Figure 6. *Structure heights and snow depths, snow pressure magnitudes, running meter weight, and costs, illustrate by the example of steel snow bridges OeAM of various installation sizes.*

5. Checking the Supporting Structures

During construction, it is well to provide the construction superintendent annually with a sketch of the arrangement of the operations (compare Figure 7) in order to orient him with regard to the installation layout. When combined, these annual structure layouts provide a survey of the entire project. In addition, these plans can be employed for the winter observations (plotting the descents of avalanches into the structures, glide cracks, snow drifts in the area, etc.), for recording damage, for the organization of operations (e.g., designation of areas for afforestation, terracing, etc.), and quite generally for recording the operations which have been carried out. It is precisely the latter which is missing today in many old projects.

When costs are as great as 0.5 million francs per hectare for permanent supporting structures, it is also advisable to have the completed structures and all their details photogrammetrically recorded; the corresponding costs for a 1:500 scale plan are about 500 francs per hectare -- for an area of 5 hectares (more expensive for smaller areas).

Plans with structure layouts and photogrammetric detailed plans of a completed project should also be supplemented by a construction cadastral survey. In the latter, which is best in tabular form, in addition to the structure number, size, and type, all worthwhile data concerning each individual structure should be recorded, such as data regarding building material, foundation, spacing, slope inclination, glide factor, episodes of damage, etc.

6. Construction Materials, Structure Types, Overall Running Meter Figures, and Manufacturers of Supporting Structures

Up until the end of the fifties, modern supporting structures were principally the following types of articulated and mass prefabricated units:

Expensive but easily transported supporting structures having light metal connections (Aluminum Company of Switzerland, Zurich, and the Aluminum Works Company, Rorschach) as well as those made of elements which are heavy but cheaper to procure, made of prestressed concrete (the Prestressed Concrete Company, Adliswil

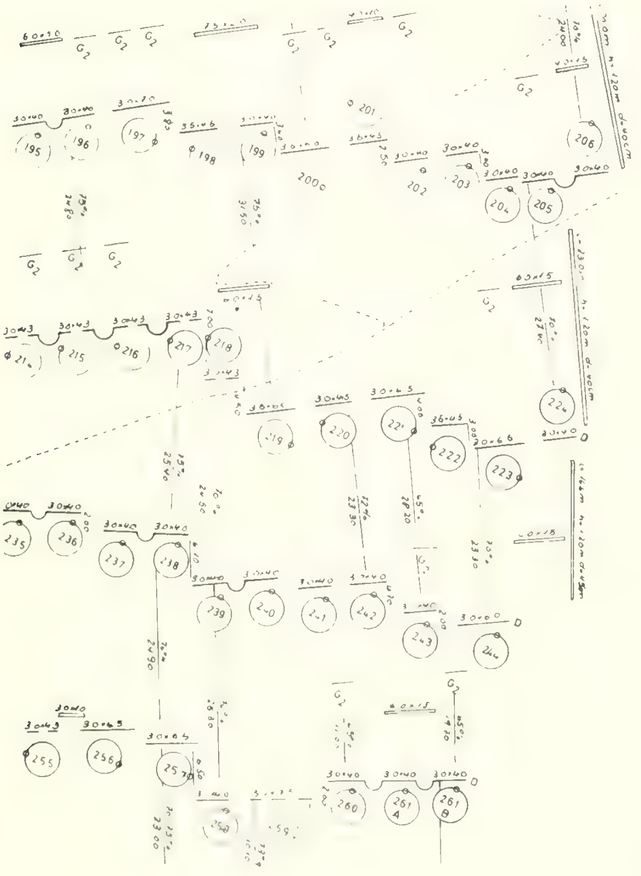


Figure 7. Excerpt from a sketch, "Installation Layouts 1:500," for the Tanngrindel/ Brienz avalanche control project.

Legend

(201)	Structure number with data regarding supplying company
———	Snow bridge
— · —	Snow rakes
3,0 × 4,0	Grid height x structure length
◡	Intermediate beam fittings
▭	Dry wall
G2	Anti-glide bridge
D	Double end beam and support
L=20m h=1,2m d=40cm ▭	Concrete separating wall

Zurich). These two materials have the essential disadvantage of displaying sensitivity to rock impact. Since the beginning of the sixties, the superstructure building materials have tended to be exclusively steel.

The most widely used type of structure today is the snow bridge. Usually the snow rake is unable to compete with snow bridges, primarily for manufacturing reasons and therefore also for reasons of cost.

The use of avalanche fences -- today principally made out of old railroad rails and a net grid -- is usually limited to old projects having walls which are made higher by a means of this type of installation.

The use of snow nets (the Brugg Cable Works Company, Brugg) has diminished because of [high] maintenance costs and deficient retarding effect and arresting capability. The introduction of loose stone anchors could augment the possibilities for employing this type of structure and together with various improvements (a different form of the compression grid), its employment could again become interesting.

In Switzerland, between 1939 and 1970, a total of 160,394 m of articulated supporting structures (including wooden structures) were constructed. In the period from 1964 to 1970, the figure was 74,843 m or about 10,700 m per year; here the quota of snow bridges and snow rakes in steel amounted to more than 6,000 m per year. Of these steel designs, the greatest part were snow bridges of the Austrian-Alpine Montan Company (OeAM) represented by Carl Stuerm and Company, Rorschach.

In addition to the manufacturers already mentioned, today the following Swiss firms are also producing permanent supporting structures:

Snow bridges: Giovanola SA, Martigny
Snow rakes: Zuellig and Company, Goldach
Snow bridges/snow rakes combined: Belloli/ Donatsch (BEDO), Cama and Landquart

7. Problems in the Boundary Zones

Boundary structures are required to support static end-effect forces which, depending upon the existing glide factor, can amount to two to five times the slope-parallel snow-compression component. In addition, there are dynamic forces which can stress the boundary of the construction area because of avalanches from adjacent uncontrolled areas.

Hence, one should strive to cover entire terrain hollows with structures and extend them laterally up to terrain ridges. But this is not always possible, and by itself is often insufficient. When it is not possible to attach the structures to a natural boundary line, protection of the construction boundary is often still not achieved by back-staggering the next lower row of structures. Instead, additional measures must be considered.

In practice, the end-effect forces are usually counteracted by installing an additional beam and support on the boundary side of the original beam and support. In the case of high glide factors, this measure by itself is often insufficient; it is necessary to build longer concrete separating walls having a height of about $H_K/2$ or concrete block of equal height must be inserted from beam to support. The separating walls substantially reduce the end-effect forces and definitely prevent the entrance of ground avalanches into the construction area.

In Austria, for relieving the boundary structures, small gliding snow bridges having a D_K = 1.0 m are also employed. In the Bernese highlands, large earth terraces are also employed for anchoring the snow cover to the surface of the ground, or niches are blasted out of the rock.

In the case of open construction boundaries there is the danger of slab fractures extending from the unconstructed zone into the constructed zone. This danger can be dealt with by building additional structures of normal size at half spacing. A possible approach, and one particularly to be recommended when there is risk of damage to the supporting structures is the construction of avalanche guidance structures (steel walls and concrete walls or earth dikes). Under some circumstances the construction of such dikes or walls can create the disadvantage of increased snow drifts in the boundary zone of the construction area.

When there is a possibility of dynamic stressing of the supporting structures in the boundary zone, it is advisable, in addition to the measures which have already been discussed, to install an additional beam and support in the middle of the compression grid in order to prevent damage to the latter.

Besides the "separation constructions" which have been mentioned and which primarily relate to the lateral boundary zone, some remarks must be made regarding the design of the lower project boundary. At least in the case of protected objects which lie near the construction area, e.g., in the protection of roads and railways, the lowest row of structures must in any case be installed continuously and with an increased grid height; in addition, thought should be given to the intro-

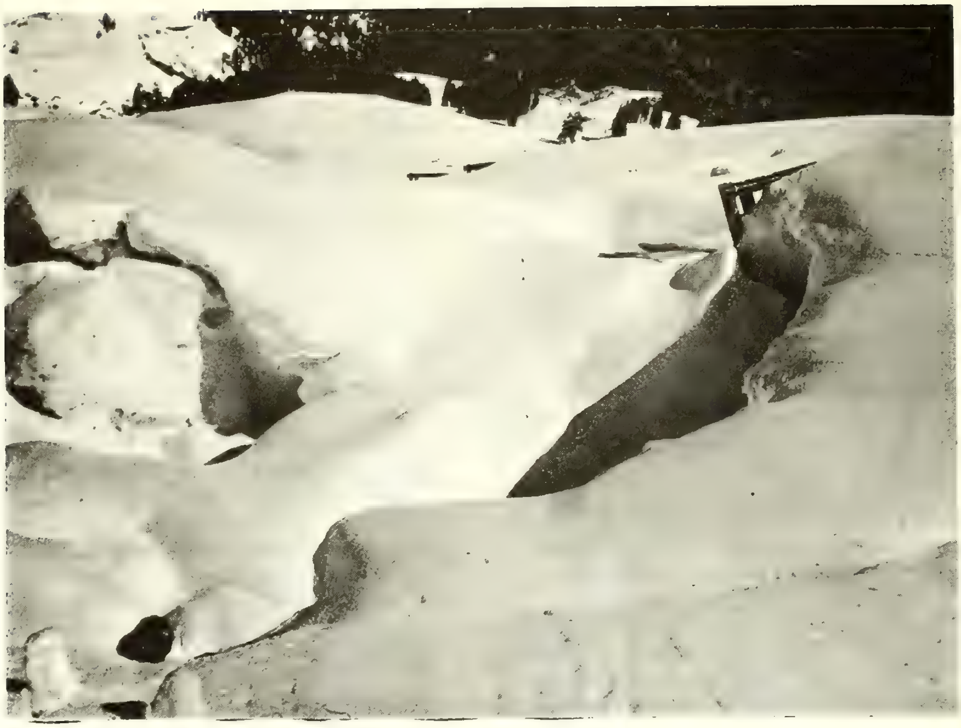


Figure 8. The gliding motion of the powerful snow masses demonstrates the great edge-effect forces which must be restrained by the supporting structures along the edge of a construction area (Tanngrindel/Brienz, photo W. Schwarz).

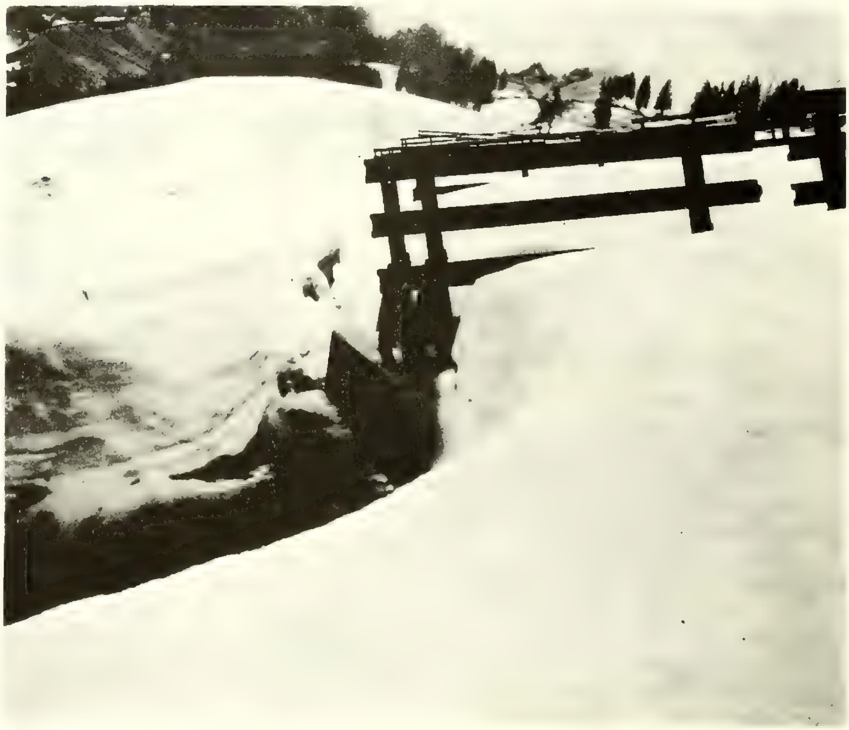


Figure 9. An OeAM snow bridge protected from edge-effect forces by means of a concrete block and a double end beam and support (Tanngrindel/Brienz, photo W. Schwarz).

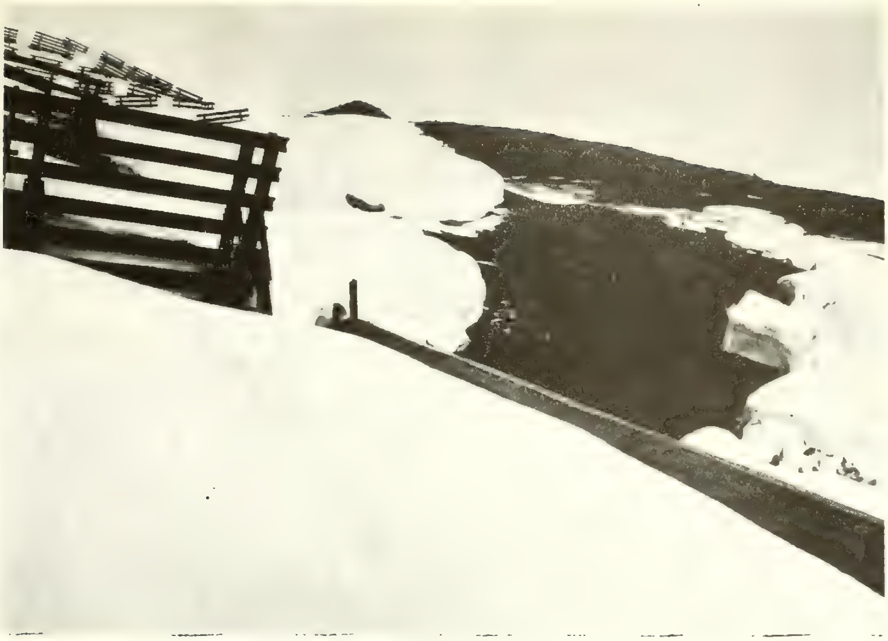


Figure 10. Concrete separating walls prevent entrance of ground avalanches and extension of gliding motions from the unconstructed into the constructed zone (Tanngrindel/Brienz, photo W. Scharz).

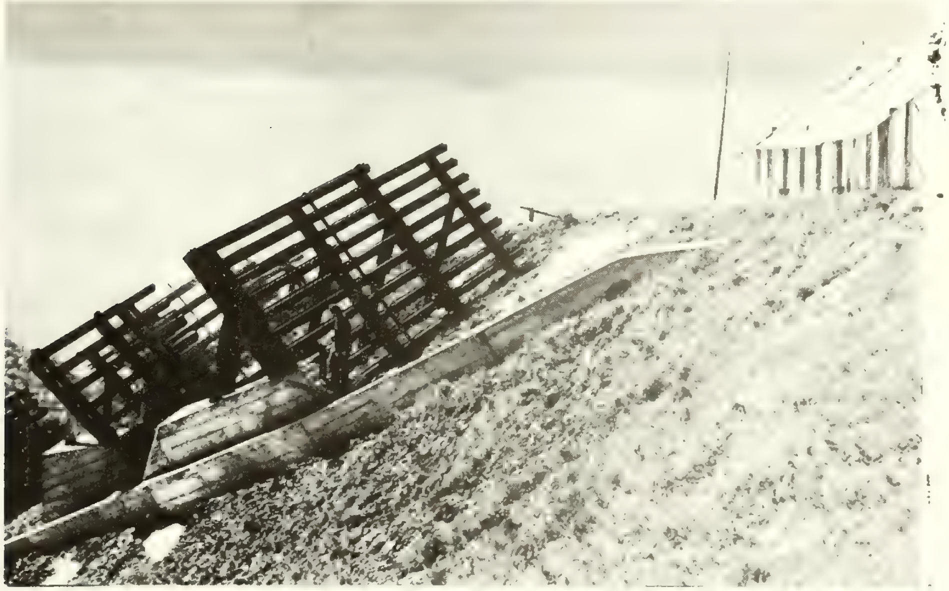


Figure 11. Concrete separating walls, concrete block, double beams and supports at the end of the structure, additional snow bridges at half spacing protect the uppermost part of the Tanngrindel/Brienz construction area from [snow movement in] the unconstructed region. Separation of the constructed from the unconstructed zone is reinforced by a jet roof (photo W. Schwarz).

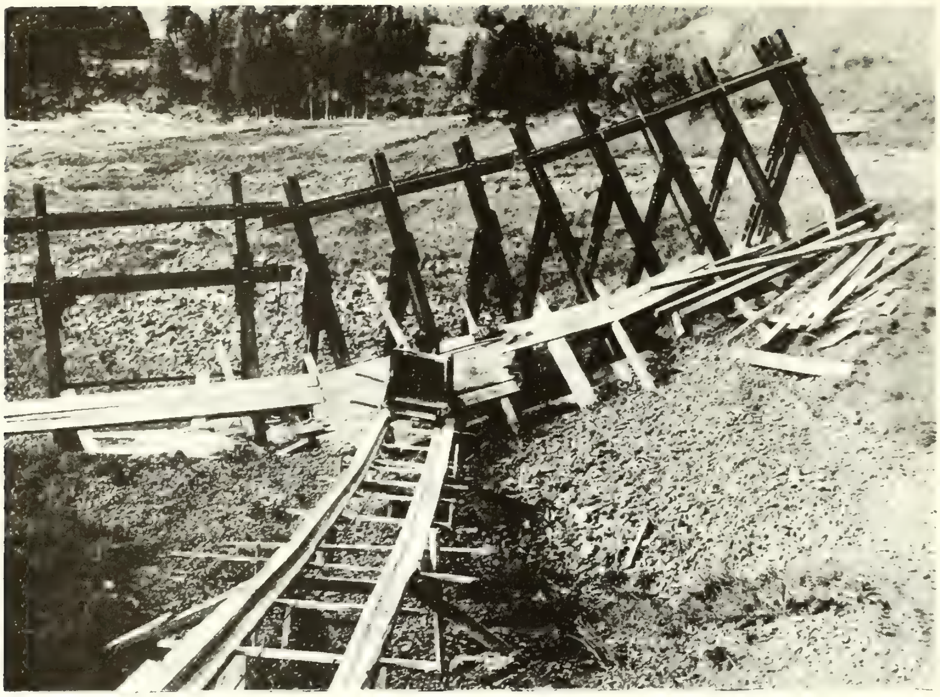


Figure 12. In construction area boundary zones, which are exposed to dynamic stressing, the endangered structures must be strengthened by installing additional beams and supports in the center of the field or be protected by other suitable measures (Wilerhorn/Brienzwiler, photo W. Schwarz).

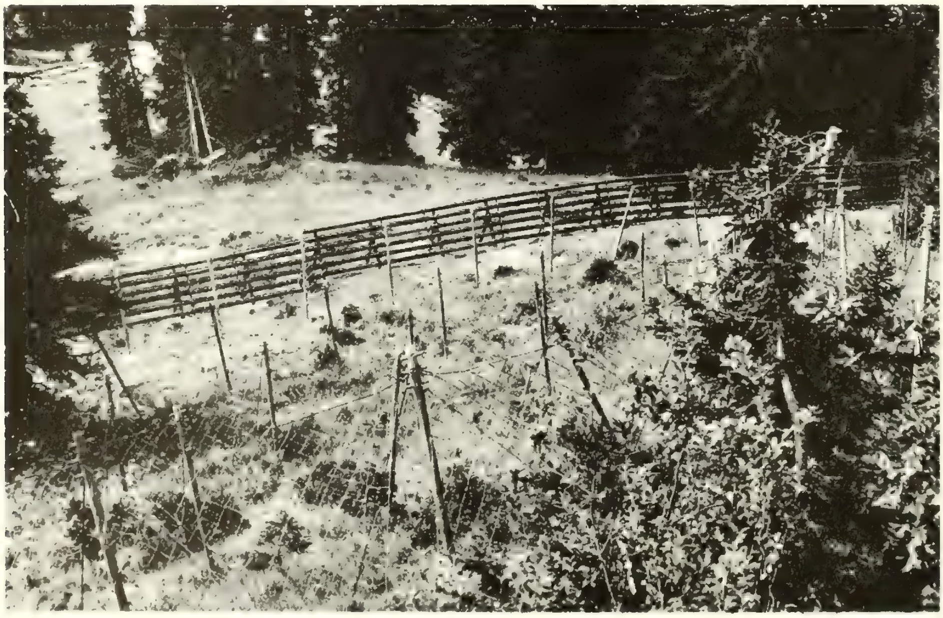


Figure 13. Snow nets (Brugg Cable Works Company), with a continuous row of steel snow bridges OeAM below (Tanngrindel/Brienz, photo W. Schwarz).

duction of a diagonal weave on the compression grid. Snow net projects are often satisfactorily closed off below by means of a row of rigid supporting structures (e.g., a continuous row of snow bridges) in order to retard and arrest any snow movements.

8. Permanent Protection Against Gliding Snow

Permanent snow glide protection is intended, in grassy southern locations having flat ground and also in locations of similar exposure having smooth superficial rock faces, for the protection of permanent structures against damage produced by gliding snow forces, and is also intended to permit afforestation on flat ground sites.

From this description, it is clear that gliding snow protection whenever possible, should be based upon conventional, temporary, cheap measures, such as flat or dished terraces, and wooden posts (compare H. in der Gand, Section 2). These latter methods assume good solid ground and are not usable in flat rocky situations. For these cases, the following two procedures have been developed for permanent gliding snow protection:

a. construction of dry walls, in some cases by resorting to wirebound stone boxes (the system employed by Hutter-Schranz, Fratelli Albertolli, Avi, etc.), having a height of about 100 cm;

b. installation of antiglide bridges OeAM with D_K = 0.6 m and 1.0 m.

For example, in the Tanngrindel/Brienz project (glide factor N = 2.9) 350 running meters of dry wall with wire-bound boxes (which simultaneously served as deposit locations for rocky excavation material) and about 500 running meters of OeAM antiglide bridges were installed for permanent gliding snow protection.

These permanent antigliding structures are placed in such a way that the spacing of the supporting structures in the fall-line is approximately halved, taking into account the shape of the terrain. In this way, in the above project, it was possible to prevent the occurrence of glide cracks.

In a number of antigliding installations, it has been established empirically that the horizontal spacing should not exceed 2-3 m since otherwise new glide cracks arise and in particular the corners of the dry walls are damaged.

Permanent gliding snow protection using dry walls and antiglide bridges is capable of reducing the movements of gliding snow within the limits of a construction area to such an extent that no further glide cracks arise. The resulting force peaks applied through the antiglide structures have not, on the basis of observations thus far, had a disadvantageous effect; it has not yet been possible to detect any slab fractures across these installations.

In constructing dry walls, consideration should also be given to a tapering in the direction of the valley and at the foundation, amounting to at least 25 percent, in order to avoid overturning of the walls by the gliding snow forces.

The OeAM antiglide bridges are manufactured for concrete foundations as well as for those employing ground plates, in structure lengths of 3 m and grid heights D_K of 0.6 m (one beam) and 1.0 m (two beams). From 1963 to the end of 1971, the OeAM produced 4,038 running meters of antiglide bridges of which 630 running meters were assembled in Switzerland. The costs today per running meter for the purchase of superstructure of the type 1.0 x 3.0 m with concrete foundation run to about 120 francs -- including freight, import charges, and sales tax, and for the completely installed structure, the cost is about 200 francs -- without material transport.

The antiglide structures 1.0 x 3.0 m having a concrete foundation have shown themselves, despite great deposits of snow, to be astonishingly resistant to damage. Of the 492 running meters of antiglide structures in the Tanngrindel/Brienz construction, since 1962 only 1.2 percent have been damaged and this was only because the rock anchorings had been torn out along with entire slabs of rock.

The employment of types having base plates is to be avoided since in the case of deep soils the protection of afforestation and the load relief of the supporting structures is more successfully accomplished by large-area terracings (stepped terraces, dished terraces, earth terraces, posts).

Figure 14. OeAM gliding snow bridges 1.0 x 3.0 m permit afforestation in sites having high glide factors and flat-ground soils and also relieve the actual supporting structures. Important for antiglide bridges is the existence of a large taper in the supports amounting to at least 35 cm/m (Tanngrindel/Brienz, photo W. Schwarz).

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English Translation of German Titles

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[2] Avalanche Control Structures.

[3] Avalanche Control Structures in Steel and Reinforced Concrete, Use of Steel, No. 316.

[4] The Limits of Modern Avalanche Control Structures in the Starting Zone.

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VII. TEMPORARY SUPPORT STRUCTURES AND GLIDING SNOW PROTECTION (Hansruedi in der Gand, Davos)

1. Temporary Supporting Structures

1.1 General Remarks

A temporary supporting structure is an anti-avalanche protective measure having a short-term period of effectiveness. In Switzerland, this type of structure is primarily employed in conjunction with the afforestation of avalanche regions. The supporting structures must, in this case, fulfill their purpose only until the growing afforestation functions independently for avalanche protection, i.e., on the average 20-40 years. Occasionally, it is necessary to provide temporary facilities (construction sites, barracks, transport facilities, etc.) with temporary avalanche protection by means of supporting structures.

The considerable reduction of required permanency for temporary supporting structures in contrast to the requirements of permanent avalanche protection structures permits the choice of cheaper and less durable building materials and more economical designs. Because of the high costs of permanent support structures (compare W. Schwarz, Section 4), this is a decisive feature for the short-term protective measures needed in regions of afforestation.

Up to now in Switzerland, it has been necessary for the majority of protective structures to be permanent. From 1939 to 1966, the 31,600 m of temporary supporting structures built amounted to only 25 percent of the total support construction [for the period] [1]. Within the framework of future installations in mountain forests and in new afforestations, temporary supporting structures will increasingly come into use (compare C. Ragaz, Article 16, and M. de Coulon, Ausblick). The limitations imposed upon the building costs of temporary support installations will thereby attain still greater economic significance.

In the pursuit of price-favorable solutions, one must not be misled into sacrificing the necessary quality of construction. The past has shown often and clearly that makeshift and unsuitably designed structures are in the long run unable to meet the severe demands of the avalanche regions. Such provisory structures easily give rise to failures and also to excess costs and in this way damage the image of temporary support construction. Practitioners -- partly on their own and partly in cooperation with the Federal Institute for Snow and Avalanche Research (EISLF) -- have repeatedly sought to construct more resistant, standard types of structures. Important principles for this purpose have been communicated to us by Prof. Dr. Haefeli in his snow engineering and avalanche construction lecture at the Federal Technical Advanced School of Zurich. Nevertheless, the development of temporary supporting structures, from the engineering point of view, did not progress very far. The practitioner had at his disposal neither the necessary principles nor the time to solve the various material, engineering, and design problems; and the EISLF was fully occupied with permanent support construction after the avalanche catastrophes of the winter 1950/51.

Therefore, it is not surprising that with the development and industrial manufacturing of prefabricated, standardized permanent supporting structures, temporary support construction suffered a certain loss of confidence. This was apparent when permanent support constructions were erected instead of temporary ones, in many places even in afforestation regions. The marked rise in cost for permanent structures, caused in part by more rigorous guidelines and in part by rising costs of material, has recently brought a halt to this uneconomic procedure. But at the same time and with good reason, there was also a call for more resistant and more economical types of structures.

The EISLF, within the context of afforestation experiments being carried out in the avalanche starting zones of the Stillberg in the Davos Dischma Valley in conjunction with the Swiss Forest Research Institute (EAFV), was confronted with the task of erecting temporary supporting structures in which the structures would have to satisfy (Figure 1) precisely these requirements: high resistance and durability at the least possible construction costs. Admittedly the new type of installation still does not have its final long-term testing behind it; but is has already proven itself in two important cases:

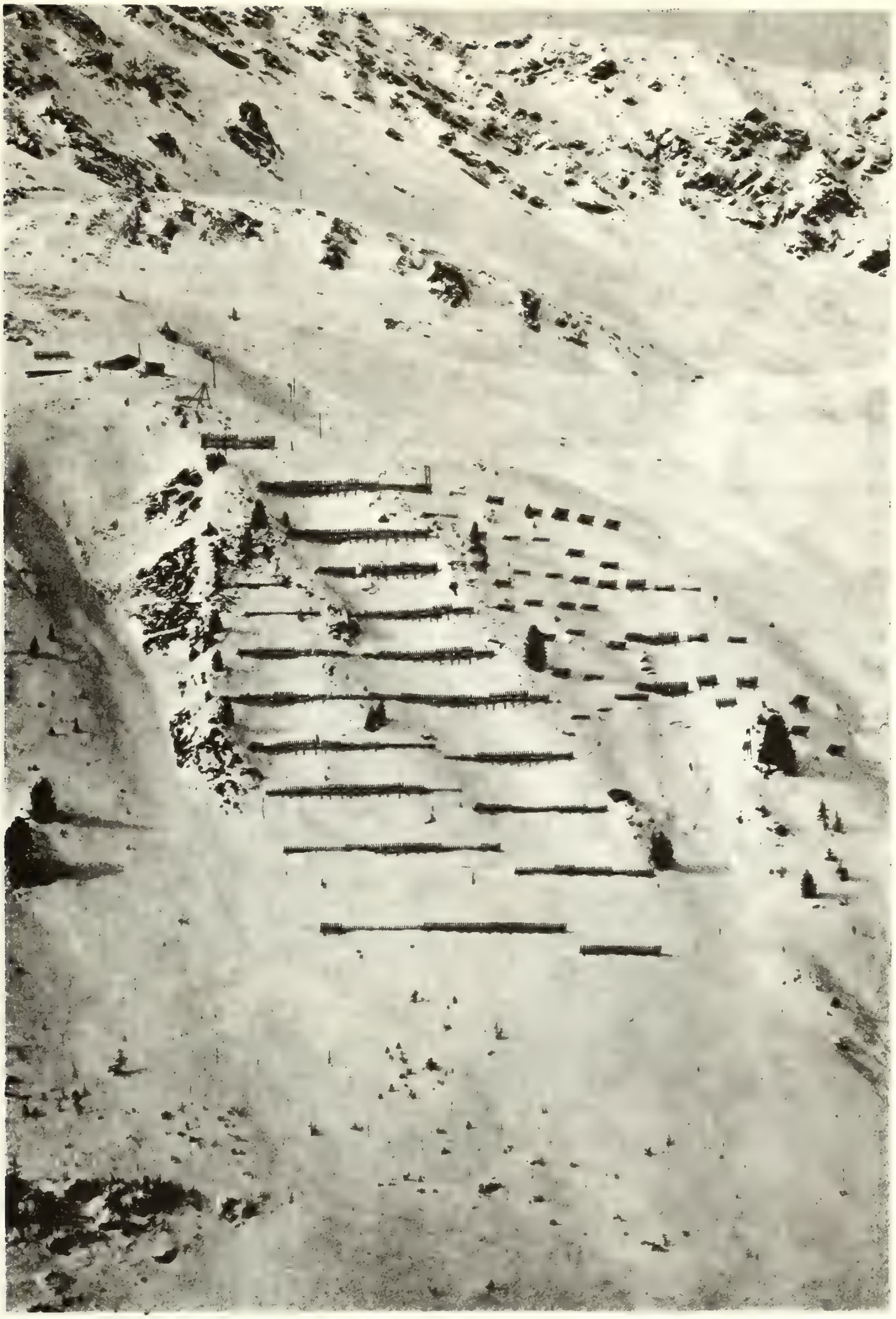

Figure 1. *Experimental region EISLF/EAFV Stillberg (Dischmatal/Davos), temporary supporting structures with round-wood snow rakes; left subarea with ready-made continuous arrangement, right subarea with discontinuous arrangement; 9 March 1972 (photo E. Wengi).*

a. in the snowy midwinter and later winter 1969/70, over a several months time span with high snow pressure, there was not a single instance of deficiency in over 300 m of supporting structures; also, slab fractures occurred only in the surrounding zones but not in the controlled region itself (Figure 2).

b. the structures survived undamaged despite high shock loadings from a wet, ground avalanche which broke loose during the extremely warm days of Easter 1971 (Figure 3).

Hence, because of the urgent need for temporary supporting structures for future afforestation and forest restoration projects, this type of structure will be employed as an example for illustrating the most important material, technical, design, and construction facts and principles which must serve as a foundation for the planning and erection of temporary supporting structures. This does not exclude future developments in temporary supporting structures.

1.2 Guidelines

The last edition (1968) of the Guidelines of the Federal Forest Inspectorate for Supporting Structures, designated "Guidelines" in the following paragraphs [2], sets the standard for both permanent and temporary supporting structures in the starting zones of avalanches. This is a consequence of the fact that both types of structures -- with the exception of the lesser durability required for the temporary support installations -- have basically the same task and effect. Therefore, temporary supporting structures must be calculated, designed, and dimensioned on the basis of the possible stresses and with attention to the material properties of the various materials employed. Thus, a

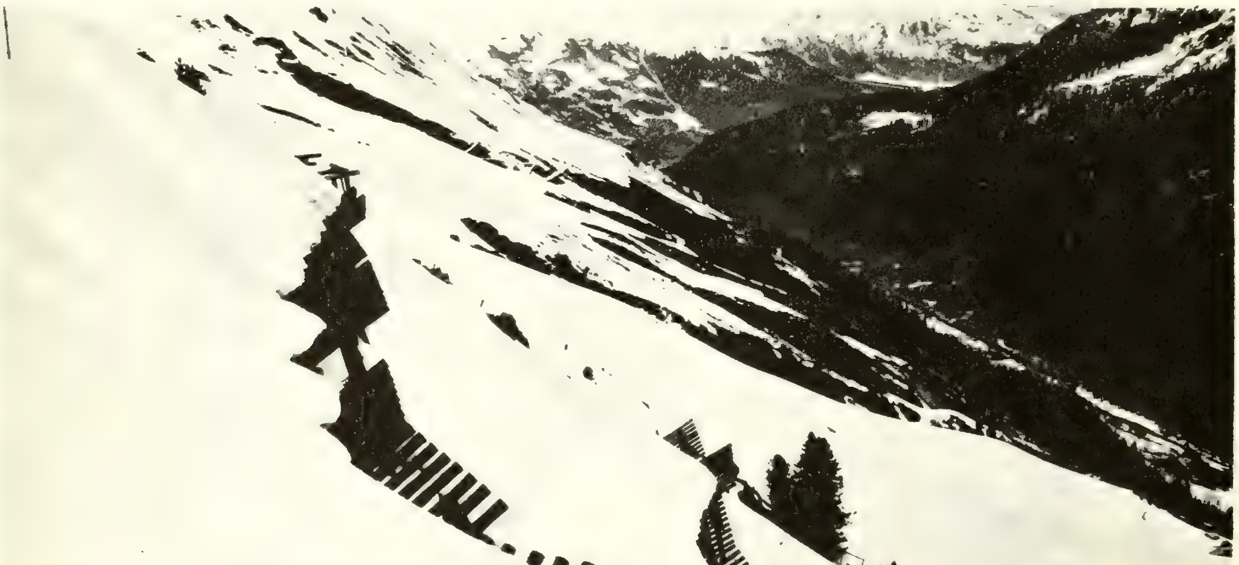

Figure 2. Experimental region in Stillberg with a continuous arrangement [of structures]: condition of the snow cover on the round-wood snow rakes on 29 May 1970 (photo E. Wengi).

temporary supporting structure is no longer, as previously, merely left to the distinctive capacity of the journeyman but properly and in analogy to permanent modes of construction, must be elevated to the rank of engineering construction. It is in this sense that the above-mentioned Guidelines now provide the principles necessary for the static computation and design of articulated, temporary supporting structures.

1.3 Building Materials

Up until today, for temporary supporting structures, wood has maintained its position as the most important and price-favorable building material. Fir, pine, larch, scotch pine, mountain fir, and chestnut are used both in the superstructure and in the lower structure, primarily in the form of round-wood. Where the wood supply is adequate, half and quarter timbers are also employed in the grids. On the other hand, so far square timbers have been used only in a few cases [3], among others in an experimental project carried out by the EISLF on the Dorfberg in Davos/Dorf, for the purpose of comparing round-wood structures. Square timber exhibits less strength than round-wood, owing to the unavoidable cutting of wood fibers during sawing [2, 4, 5, 6] and involves higher material costs. Therefore, it will probably not play a significant role in temporary supporting structures in the future as a construction wood although untreated, unsplintered square timber is less subject to rot than unimpregnated round-wood.

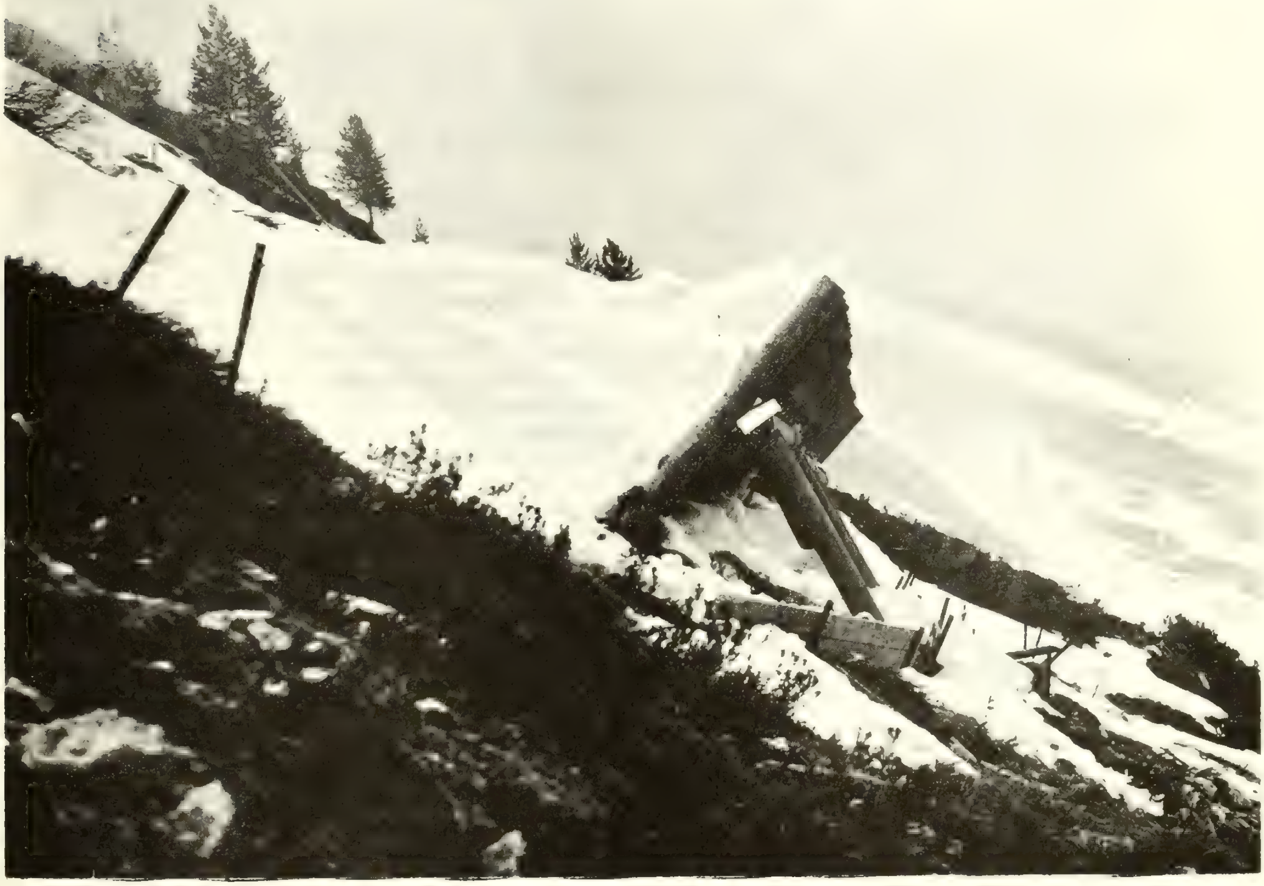

Figure 3. Experimental region on the Stillberg with continuous arrangement of structures: snow deposit by the wet, ground avalanche of 22 April 1971 on the uphill side of the lowest row of structures, 3 May 1971 (photo J. Rychetnik).

Wood is a naturally growing construction material whose material properties, depending upon growth conditions, can display a wide range even for the same species. Besides excellent structural characteristics, wood also possesses some deficiencies which limit its utility. Therefore, a fundamental knowledge of the material is a prerequisite for technically and economically correct utilization of wood. This applies particularly to the severe conditions to which wood is exposed in temporary supporting structures.

We shall briefly list [5, 6, 7] the essential structural advantages and disadvantages of wood with respect to temporary supporting structures.

Important advantages of wood:

a. relatively low material cost in comparison with other building materials;

b. high compressive and tensile strength under stress in the fiber direction;

c. good chemical corrosion resistance in soil compared with other building materials used for supporting structures. This is an advantage when construction components are installed in soil;

d. easy workability both on the workbench and at the building site, so that necessary adaptations of the structural elements may be carried out right on the site without great alterations and additional costs;

e. relatively low weight compared with its strength, which contributes to simplification and cheapening of transport and assembly operations;

f. simple and cheap assembly with nails as fastenings and the short construction time which is guaranteed by the dry mode of construction, all of which favor construction progress and construction costs especially in the mountains with their climatically short building periods;

g. in certain cases, the acquisition of wood in the vicinity of the construction site can also be advantageous with respect to transportation and with respect to scheduling procurement of the building material.

Structural disadvantages of wood:

a. possible destruction, especially by fungi, which necessitates improving the durability by special wood protective measures (compare Section 1.4);

b. the marked variability of strength and deformability of wood depending upon various factors such as growth conditions, volumetric weight, water content, wood defects, etc., which impose rigorous standards in establishing allowable stresses and, in the selection of the wood, to eliminate diseased, defective, contorted, boxy, and branchy material [2, 4-10];

c. the necessity of selecting and tailoring the required dimensions to the available assortments.

In addition to wood, one also finds other building materials in temporary supporting structures:

a. prefabricated, armored concrete plates and natural stone plates for the foundations;

b. iron pilings for anchoring structures to the mountainside;

c. nails, wood screws, bolts, and iron bands employed as fasteners.

1.4 Protection of Wood

Most of our wood varieties which are likely to be employed in supporting structures are attacked by fungi when left unprotected in the open. Insects, especially long-horned beetles [Cerambycidae] are occasionally secondary wood destroyers of subordinate significance. The wood-destroying fungi possess the specific capability of decomposing the skeletal substance of the cell walls (cellulose) and the lignin and using these as nourishment. This decomposition of the wood, known as rot, manifests itself in a sharp reduction of wood strength and ends with complete disintegration of the wood. Wood rot manifests itself far beyond the boundaries of the forest and can, despite reduced propagation rates in the high altitudes and under inferior living conditions for the fungi, still produce great damage in moist unprotected wood. On the Dorfberg in Davos and on the Schilt/Toggenburg, in avalanche structures and afforestation within and above the forest zone a total of more than 20 different varieties of wood-destroying fungi were observed in wooden protective structures [11]. Wood decay is also the chief reason for the complete displacement of wood as a building material from all permanent avalanche protective structures and it compels the use of special wood protective measures in temporary supporting structures. They all are designed to conserve the functional capability of the wood structures for a period of 20-40 years and therefore are of decisive significance [11-15] in temporary supporting structures.

The process of wood protection begins in the selection of the construction wood. Here it should be noted that the natural resistance of the wood to fungal attack can display considerable variability depending upon the type of wood and also depending upon whether one is dealing with heartwood or sapwood. Of better durability are the heartwoods of chestnut, oak, scotch fir, mountain fir, and larch. Spruce, pine, and scotch fir sapwood are less fungus resistant; larch and oak sapwood are highly susceptible to fungal attack. Snow rakes of spruce began to disintegrate owing to wood rot after as little as 5 years; this was on the Schilt/Toggenburg at 1,500 m on a north slope having heavy precipitation. On the southern exposure of the Dorfberg near Davos at an elevation of over 2,300 m, horizontal spruce beams rotted within 10 years to the point of being unusable. On the other hand, in the construction and afforestation region of Selva-St. Brida at an elevation of 1,800 m chestnut heartwood built into snow rakes in the year 1943 on a southeast slope were still functional even after a period of 25 years. Hence, for longer durability of the structures and for especially endangered structural elements, there is advantage is selecting more durable woods. It goes without saying that only healthy wood should be used. But without a detailed investigation, it is often impossible to establish the existence of fungal attack. For this reason, it is important to obtain assurance that the wood has been rapidly and expertly prepared and in certain cases, has been dry-stored after felling and up to the time of its inspection for construction purposes. In doubtful cases, sampling investigations should be carried out.

Additional important wood protective measures are of a constructive nature. Here it is a matter of excluding as much as possible the collection of water and of excluding the longer lasting increase in wood moisture, as compared with that of dry wood, by suitable arrangement of the wood elements and of the fastenings. High wood moisture is the essential prerequisite for the development of fungus. Optimal conditions, depending on the type of fungus, range from a water content of 20 percent to 60 percent of the dry weight of the wood. Below 15 to 20 percent, no growth of wood-destroying fungi is possible.

The most important constructive [design] protective measures are (compare Figure 4):

a. a predominantly standing or inclined arrangement of the supports, grid beams, and diagonal braces, so that rain and melt water remain for a lesser time. For the same reason, in wood structures, the snow rake with its inclined grid elements is to be preferred to the snow bridge with its horizontal grid elements.

b. an aluminum or sheet iron covering arranged over all horizontal wooden stringers that include corewood [1] so that air can circulate between the metal and the wood in order to avoid as much as possible the penetration and stagnation of rain and melt water. These measures were applied, with good results, for the first time by Chief Town Forester J. Kuster, in St. Gallen, on the Schilt/Toggenburg.

c. the avoidance of unnecessarily large, wood pieces that include corewood by designing the wood elements in accordance with the results of the static calculation. Thicker wood pieces that include corewood are more markedly exposed to fungal attack than are thinner pieces that do not include corewood. This is related, among other things, to the fact that thinner wood dries out faster than thicker wood and that cross-sections without corewood are less disposed to the formation of dry cracks and hence are less inclined to water stagnation than is the case with cross-sections that include corewood. Therefore, to the extent that thicker pieces can be employed, it is advantageous to install them as half rounds or quarter rounds and moreover with their round sides downward in order that water shall be unable to accumulate in the cracks. In addition, the supporting capacity of the half rounds is better in this position than when the cut surface is downward because the stress distribution leads to larger tensile stress and smaller compressive stress which introduces greater load-carrying capacity in view of the much higher tensile strength of the wood.

d. it would also be advantageous to raise the entire wood construction above the ground in such a way that it lies outside the moister zone in the vicinity of the ground. But this is not realizable because of the substantial increase in the cost of the foundations which would be associated with such a procedure. But something like this cannot be avoided, without increasing costs, in connection with the stringer positions on the upper support end, which permits the penetration of water into the cross-cut end. In these cases, one must employ artificial protective measures to deal with the susceptibility of the components to rot.

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[1] corewood: the juvenile wood immediately surrounding the pith.

A final important measure, which is very effective when properly used is artificial wood protection. This involves the introduction of fungicides into the wood structure so the development of fungi is prevented or adequately delayed. This wood impregnation must always be employed whenever the natural durability of the wood is too short compared to the required useful life. When spruce and pine are used, this may be necessary for a useful life of more than 5 years and in the case of chestnut, for a life of more than 20 years. In addition, wood must be impregnated in every case when it has not been adequately protected by design provisions in the construction itself. Depending upon the useful life of the supporting structures and upon the resistance of the wood, this [need for protection] applies to horizontal stringers, the lower part of grid beams and supports, as well as ties that are near or in contact with the ground, and moreover, applies to exposed locations where stringers are attached to supports, and to exposed cross-cut ends of grid beams and diagonal braces.

In order to obtain an appropriate and economic wood impregnation, protective agent and mode of employing it should be selected in accordance with the time limits imposed upon the structures in the installation. There are available for the purpose of wood protection such agents as water soluble salts, oils, protective agents dissolved in organic solvents, oil-salt mixtures, and emulsions.

The wood protective agent should exhibit the following characteristics:

a. good fungicidal effectiveness against brown rot and mold rot; minimal toxicity for humans, animals, and the vegetation cover, during and after application;

b. good water solubility (salts) and diffusion capability as well as good storage capability and resistance to washing out;

c. good penetration depth for the existing water content of the wood, and low metallic corrosion.

Possible impregnation procedures:

a. manual procedures:

immersion soaking over several days
osmotic processes
salt wrappings or oil-salt wrappings as an additional protection for wood which is in contact with the ground

Charring, painting, spraying, and dipping give inadequate protection and therefore may not be considered for wood impregnation in supporting structures.

b. industrial procedures:

pressure kettle procedures
sap-displacement procedures (Boucherie technique, open-tank soaking, suction procedures, alternating pressure procedures)

Besides the nature of the wood and local conditions, the impregnation procedure is determined especially by the durability required of the supporting structures. Wood having inadequate natural durability, in order to attain a useful life between 5 and 15 years must be protected at least by means of a soaking over several days. A useful life of more than 15 years is obtainable by means of correct application of the manual osmotic process or of the industrial processes. For telephone poles, today it is expected that industrially impregnated wood will have a useful life of 33 years. In temporary supporting structures, it is probable that the durability of wood treated in this way, when subjected to less exacting elimination criteria, will be still higher.

But the effectiveness of wood treatment depends not only upon the quality of the protective agent and the method of introducing it, but also very essentially upon the state and the impregnability of the wood. Thus, oily protective agents should be applied only to air dried wood, while with water soluble salts, the best protective effect is achieved when they are introduced into sappy wood. In addition, air dried spruce and pine cannot be impregnated as deeply with oily protective agents as can sappy woods with salt agents. In this case, scotch fir and larch sapwood behave more satisfactorily. In addition, a marked tendency of air dried wood to crack improves the penetration of the protective agent.

In general, a good deep protection adequate for long-term useful life of the wood is obtained only by the osmotic, the industrial pressure kettle, and sap-displacement processes. Especial attention must be paid to adequate impregnation of construction components inserted into the ground. As experiments with telephone poles have shown, a substantial increase in protective effect is achieved by applying salt-wrappings and protective soakings for a reimpregnation of dry cracks. With the object of further improving the protection of specially exposed zones, when wood is cut to fit at supports and connection locations, these processes should be carried out before the impregnation or at least retreated with suitable protective agents [after they are cut].

The artificial protection of wood must, therefore, corresponding to the conditions and possibilities prevailing at the site, be thoroughly planned if there is to be an effective and economic selection of wood, protective agents, and protective procedures adapted to the duration of the structures. The costs of wood impregnation are not low. In the case of industrial processes, they can be as high as the price of the wood itself; manual procedures are on the whole substantially cheaper [15]. But, evaluated in terms of the protective function of a temporary supporting structure, it would be irresponsible to select the method of wood impregnation only on the basis of its cost. Similarly, under normal conditions deficient planning and hence lack of time should not be allowed to make it impossible to use the best protective treatment.

It is intended that this exposition of the most important principles of wood protection in temporary supporting structures should bring out with sufficient clarity the fact that a mastery of manifold material is of basic importance for the use of wood in open-air construction and requires a solid background of knowledge.

In order to enlarge our knowledge of the effectiveness of various types of wood protecting methods under natural environmental conditions and thereby to aid practical avalanche structural control, the EISLF, together with the Wood Division of the Federal Material Testing and Research Institute (EMPA) in Duebendorf and in conjunction with the Division of Material Biology of the EMPA in St. Gallen, instituted large-scale field investigations many years ago in order to determine the most suitable wood protection techniques for avalanche control structures. The first results of these experiments will be published elsewhere in the near future. In addition, the practitioner can get advice from the EISLF with regard to problems arising in wood protection, insofar as the state of knowledge permits.

1.5 Installation Type (Figures 4 and 5)

For a long time now preference has been given in articulated temporary supporting structures to round-wood snow rakes with their grid beams arranged perpendicular to the contours and having horizontal grid timbers. The reason for this lies in the simpler anchoring, on the uphill side, of the tie over the entire installation length. In the case of snow bridges, the snow-pressure forces are applied via the grid to two carriers and the process of anchoring these carriers with adequate tensile strength on the uphill side introduces more construction difficulties. In addition, the skew-standing grid timbers of the snow rake are substantially less exposed to rot than the horizontal grid beams of the snow bridge (compare Section 1.4). And finally, in afforestations, when small trees grow up through the snow rakes, less damage occurs to them than when the branches are bent over the grid beams of snow bridges.

In the following, we therefore limit ourselves to a discussion of the most important construction features of the round-wood snow rake, turning to the SLF type of structure for illustration. This type of structure has been further developed from traditional designs and has been conceived and designed on the strength of a statistical calculation based upon the Guidelines and also on the strength of the principles of wood construction engineering and the principles of wood protection [16, 17, 18].

The snow rake consists of the grid, the main framework, and the foundations on the uphill and downhill sides.

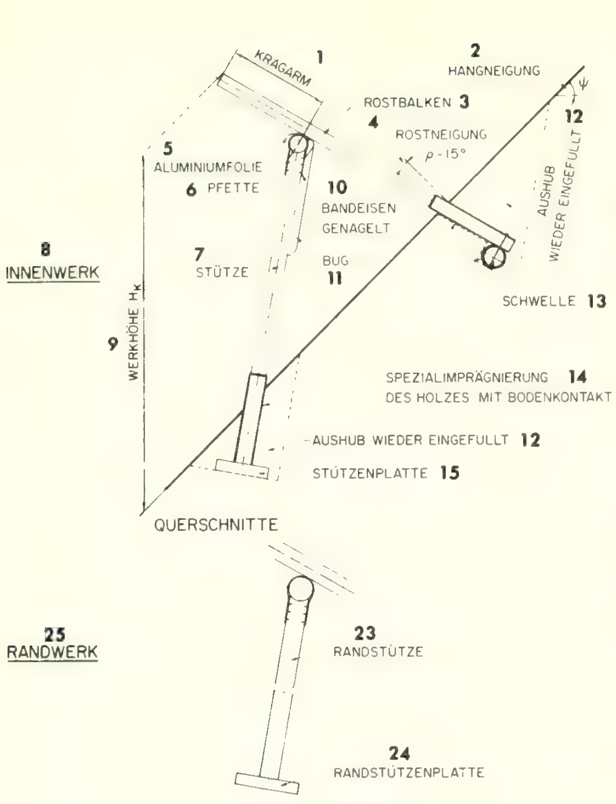
The grid (together with the grid beams, which as we have already mentioned, are perpendicular to the contours -- corresponding to the Guideline recommendation for rigid support surfaces) is inclined 15° downhill from the perpendicular to the slope. A sharply inclined grid, of the sort which was normally built in former times, displays the following disadvantages, some of which are serious:

a. with increasing downhill inclination of the grid, snow pressure increases.

b. snow rakes having a sharply inclined grid are more easily overrun by snow slides; this can also give rise to more extended avalanche invasions into a controlled area.

c. the snow overflowing the rakes transmits additional shear forces to the grid so that the foundation forces, particularly the tensile forces, are also increased.

d. with increasing grid inclination, the amount of wood in the structure increases (longer and thicker grid beams).



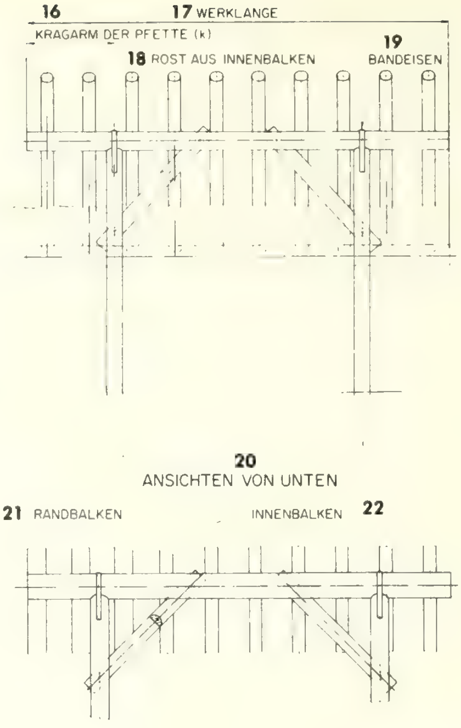


Figure 4. Round-wood snow rake SLF Stillberg/ Davos Construction glide factor 1.2 height factor 1.13

Key to Figure 4:

1. Cantilever [overhang]
2. Slope inclination
3. Grid-beam
4. Grid inclination
5. Aluminum foil
6. Stringer or Purlin
7. Support
8. Internal structure
9. Structure height
10. Nailed steel strap
11. Cross-brace
12. Refilled excavation
13. Tie
14. Special impregnation of the wood which is in contact with the ground
15. Support plate
16. Stringer cantilever
17. Structure length
18. Grid of interior beams
19. Steel straps
20. View from below
21. End beams
22. Interior beams
23. End support
24. End support plate
25. End or boundary structure

Opposed to these disadvantages, there is the insignificant advantage of a relatively small reduction in the tensile force acting on the uphill foundation. Hence, a grid inclination greater than that given in the Guidelines should be rejected.

The grid beams have been designed as freely supported carriers having a one-sided cantilever directed downhill. In order to obtain grid beam cross-sections which are as low as possible (wood protection), the design is based upon equilibrated bending moments. The grid transmits the forces of the snow pressure which act upon it to the main framework, i.e., uphill to the tie and downhill to stringers and supports. In the type of construction which has been conventional thus far, the tie -- both as a part of the main framework and at the same time as an uphill rake foundation -- lies in the open on a terrace which is at least 1 m broad and is anchored in the ground by wood pilings or iron pilings. The pilings are approximately perpendicular to the

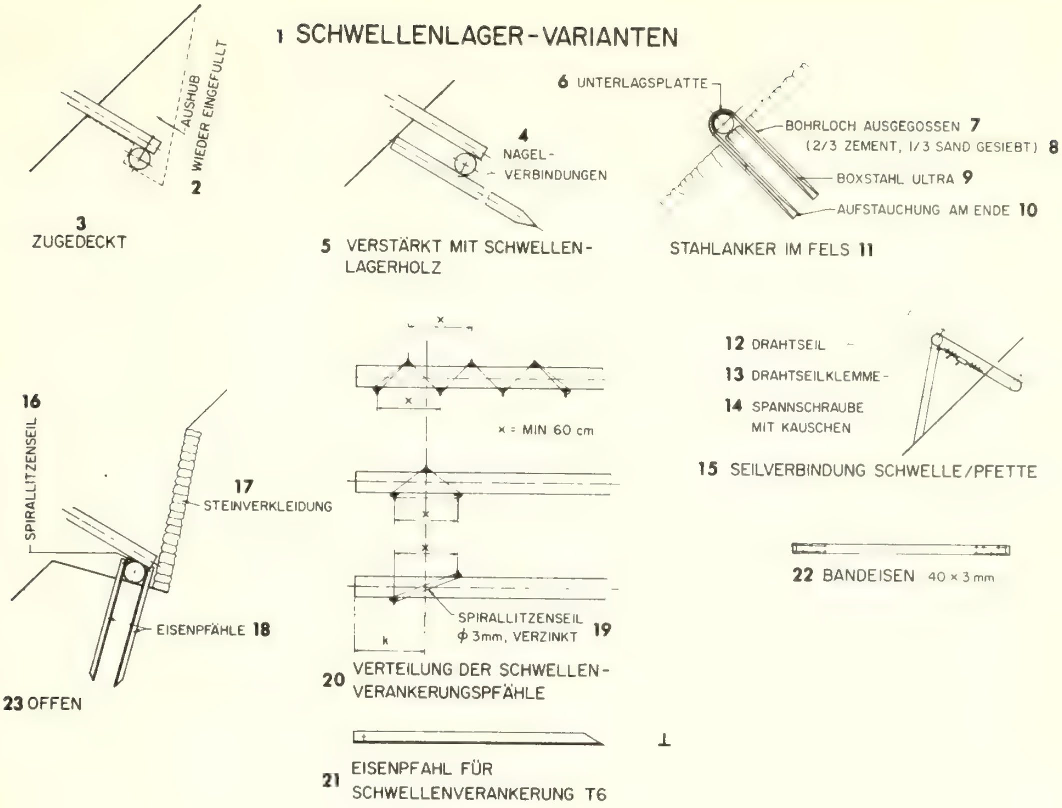


Figure 5. Details of the round-wood snow rake SLF Stillberg/Davos Construction.

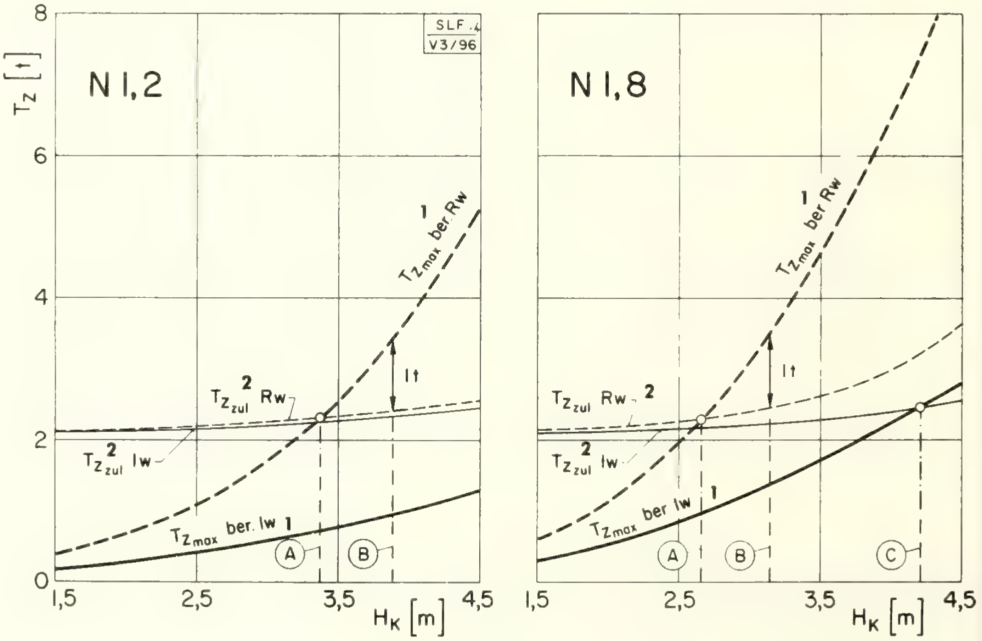
Key to Figure 5:

1. Tie support variations
2. Refilled excavation
3. Covered
4. Nail fastenings
5. Strengthened with tie-support wood
6. Base plate
7. Drill hole filled with (See 8)
8. 2/3 cement, 1/3 sieved sand
9. Ultra-box-steel [Boxstahl ultra]
10. Edge-rolled on the end
11. Steel anchoring in rock
12. Wire cable
13. Wire cable clamp
14. Turnbuckle
15. Tie/stringer cable connection
16. Spirally stranded cable
17. Stone mantle
18. Steel pilings
19. Spirally stranded cable
20. Distribution of the tie anchoring
21. Steel piling for tie anchoring
22. Steel strap
23. Open

grid plane and driven at least 1 m deep into undisturbed soil and arranged along the tie, uphill and downhill, in such a manner that their ranges of effectiveness overlap on the ground as little as possible. In order to assure a distribution of the applied foundation forces that is as uniform as possible upon all pilings, the latter are connected to one another by a spirally stranded cable (compare Figure 5). Even in the case of careful design, this type of foundation has, in experience, had low tensile strength. It is the weakest part of the entire construction and has, in various ways, been the source of damage to the structures particularly when high snow pressures resulting from gliding snow action are applied over a long period of time or when high momentary shock loadings produced by snow movements are applied to such snow rakes. In addition, computation principles are lacking for designing the piling anchor in accordance with snow pressure and strength of the soil. Therefore, the Guidelines specify for this case that in localities having marked gliding activity the tensile force acting on a tie should be reduced by artificially increasing the ground roughness (terraces, pilings). Further, such installations should not be erected in terrain which is too steep and in excessively deep snow, unless the foundations have been specially designed for the tensile forces.

Such a possibility of installing uphill foundations strong in tension presents itself when the tie is placed in undisturbed soil at a perpendicularly measured foundation depth of at least 1 m and with replacement of excavated material into the foundation diggings, with the lowest part of the support grid also being covered (compare Figure 5, variants of covered tie supports). The foundation tensile force acting in the direction of the support grid plane and applied to the tie should, in this case, not exceed the strength of the soil. The Guidelines give the principles of computation for designing uphill foundations to resist ground tensile forces. Here it should be noted that it will in general probably be difficult to install the several-meters-long tie completely in undisturbed soil and hence in the interest of safety one should assign an admissible shear stress to the ground which is equal only to that of the replaced excavation material (0.50 t/m^2 in 1 m foundation depth).

Figure 6 compares the allowable tensile components of the uphill foundation force and the maximum values of the same as calculated according to the Guidelines -- in the form in which they arise for half boundary structures or interior structures of a 4-m-long snow rake having perpendicular height from 1.5 m to 4.5 m, and whose tie is installed for 0.8 m in the ground in the direction of the grid plane. The left part of the diagram is valid for the case without gliding of the snow cover on the ground (N = 1.2), the right side for that with moderate snow gliding, such as that which still occurs initially under average local conditions, for example, in an afforestation carried out with large planting holes (dished terraces, compare Section 2.3.2) (N = 1.8). The maximum perpendicular structure height H_K for end structures and interior structures is given at the intersection point of the corresponding maximum value curves with the associated curves of allowable tensile force. Table 1 also displays the most important results of this study.



Key:

1. Computed tension component for end (RW) and interior (IW) structures
2. Allowable tension component for end (RW) and for interior (IW) structures

Figure 6. Computed maximum and allowable tension components T_Z of the foundation force T acting on the tie of a snow rake (tie installation in the grid plane to a depth of 0.8 m in the ground). This is shown for the half (1/2 = 2 m) end installations (RW) or for the inner installation (IW), for installation heights H_K 1.5-4.5 m and for glide factors (N)/height factors (fc) N=1.2/fc=1.13, N=1.8/fc=1.02

Table 1. Allowable Structure Heights H_K [m] for Snow Rakes of the SLF Type With Structure Lengths of 4.0 m in the Case of an Open Tie and in the Case of a Tie Introduced to a Depth of 0.8 m Into the Soil in the Direction of the Grid Plane, for N=1.2/fc=1.13 and N=1.8/fc=1.02; RW = end structures, IW = interior structures; assumed value of the admissible tensile stress of the piling anchoring = 1 t per 1/2 structure; ABC compare Figure 6.

Key:

1. Open tie, with piling anchor
2. Tie introduced into the soil
3. Without piling anchor
4. With piling anchor

N	Schwelle offen, mit Pfahlverankerung 1		2 Schwelle im Boden eingebaut			
			ohne Pfahlverankerung 3		mit Pfahlverankerung 4	
	RW	IW	RW A	IW C	RW B	IW
1,2	2,4	4,0	3,3	≧4,5	3,8	≧4,5
1,8	1,8	2,6	2,6	4,2	3,1	≧4,5

In summary:

a. By introducing the tie into the ground, one obtains in the case of snow rake construction not only a substantially stronger anchoring in tension than in the case of an open tie but one can also, as a consequence of this better tensile foundation, erect structural types having a greater height; and this is also the case when one takes into account the required wood cross-sections. Thus, e.g., a well constructed interior structure having height of 4.2 m and computed for a glide factor of N = 1.8 displays the following minimum timber diameters: grid beams 16 cm, tie 20 cm, supports (4 m long) 19 cm, stringer 24 cm. As the heaviest structural element of this assortment, the stringer weighs about 100 kg.

b. The decision as to whether a snow rake should be designed with a tie built into the ground or with an open tie which has been anchored with pilings is a decision which can be made only on the basis of a computation of the maximum possible tensile forces for given conditions at the site and of the allowable tensile forces with a tie which has been built into the ground.

c. In the case of piling anchors, no matter whether for an open tie or for a tie built into the ground, one must resort to empirical values with regard to the tensile strength of such anchors.

Further advantages of installing the tie into the ground are:

a. Limitation, for the duration of the construction process, of the danger of subsequent sliding of the slope when the latter has been excavated for the foundations; this sliding can occur in particularly exposed terrain zones as a consequence of continuous successive placement of individual prefabricated structures;

b. A reduction in the danger of sagging of the tie support owing to reduced water infiltration;

c. An increase in the lateral stiffness of the snow rake;

d. Absence of the necessity for terrace maintenance.

In addition to the tension forces, the uphill rake foundation must also be designed to resist the ground compression forces in accordance with the Guidelines. Where the admissible soil compression of loose rock is too low, in order to strengthen the tie support, support timbers should be rammed into the undisturbed soil (compare Figure 5) as deeply as possible beneath the tie in the direction of the support grid plane.

In the interest of completeness, we shall also list here the process of anchoring the ties in the adjacent rock by means of steel anchors, as is also shown in Figure 5. It is also possible to use cable anchors in place of steel anchors to simplify the drilling operation.

The downhill main framework of the snow rake consists of a stringer running in the direction of the contour and two supports. The stringer lies -- in the shape of a double cantilever -- directly on top of the supports. In order to obtain minimal stringer cross-sections as required for the purpose of wood protection, the stringer design is carried out, as in the case of the grid beams, on the principle of equilibrated bending moments. Likewise in the case of the supports, the minimum required diameter should be derived by determining the support length at the structure site and on the basis of buckling calculations in accordance with the Guidelines. The stringer connection at the upper end of the support should be adapted as well as possible to the form and the diameter of the stringer. By careful fitting with a bow-saw and with the aid of a circular segment template corresponding to the particular stringer diameter at the bearing location, this adaptation can be carried out without difficulty at the building site itself. Wedge-shaped stringer bearings are undesirable; they lead to a splitting of the heads of the supports.

For the purpose of stiffening the main framework against lateral loading, two diagonal braces per installation are arranged on the uphill side between the supports and the stringer. Diagonal braces for the purpose of protecting the grid are more effectively positioned and flexurally stronger than the long swivelable slats which previously were employed on the downhill side of the supports. Stiffening slats attached to the uphill side of the grid which magnify the frictional resistance of the grid and hence increase the forces acting on the structure in the event of snow motions are not advisable.

Normally, armored concrete plates serve as support foundations; their base areas should be designed in accordance with the admissible ground compression in the direction of the force. The support stands with its foot directly upon the foundation plate; its position is made secure by means of an iron mandrel placed in the middle of the foundation plate and penetrating the central drill hole in the foot of the support. In order to reduce water infiltration in the ground abutment of the support foundation and in order to increase the lateral stiffness of the rake construction, the support foundation holes can be covered over again with the excavation material. In this case, the lower part of the supports which is embedded in the ground must be specially protected against rot, as in the case of a tie inserted into the ground (compare Section 14); however, in the latter case, the steep cutting of the slope or covering with stone and the maintenance of the support holes is not required.

For the connections of support grid and main framework as well as of the structural elements of the main framework among themselves, nails are employed having a cylindrical shaft and a circular cross-section. Nail fastenings are cheaper than bolt or screw fastenings; usually they can be carried out quickly by any worker at any work location using the simplest tool, without preliminary drilling in dry and in wet wood.

We have requested the Wood Division of the Federal Material Testing and Experimental Institute for Industry, Architecture, and Trade (EMPA), Duebendorf (department head: Prof. H. Kuehne) to carry out loading experiments with nail fastenings in round timbers, as they occur in round-timber snow rakes. On the basis of the results of these experiments [19], H. Straessler makes the following recommendations [20]:

"a) General Remarks: The SIA Standards No. 164 contain no data regarding the nailing of round timbers; according to DIN Standard 1052 the allowable carrying force for the fastening of thick planks, square timber, etc., to round timber should be reduced to two-thirds their value and nail fastenings of two round timbers are not allowable in the case of load-carrying structures. Thus in previously constructed round-timber snow rakes 'unallowed' nail fastenings were employed; nevertheless they have thus far proven satisfactory in practical use.

"b) Allowable Holding Strength: Experiments carried out by the EMPA with nail fastenings [19] (per fastening, two nails 8.5/300 without preliminary drilling and driven in by means of hammer blows) between tie round timbers and grid beam round timbers exhibited substantial displacements for values of tensile force per nail amounting to 400 kg and above. In our view, a factor of safety of at least 1.5 should be maintained against this creep-load. Thus, the allowable load per nail 8.5/300 mm would have to be set at 250 kg. The following table contains the converted holding strength for the nails employed in the construction of round-timber snow rakes.

Table 2. Holding Strength of Nails for Round-Timber Snow Rakes

Nagel-Typ ϕ / Längen [mm] 1	4 zulässige Tragkraft pro Nagel bei Scherbeanspruchung	
	gemäss Formel in den S.I.A.-Normen 164 [keine Abminderung wegen Rundholz-Anschlüssen] 2	geschätzt auf Grund von Belastungsversuchen der EMPA 3
8,5/300, 275	199 kg	250 kg
7,5/260, 245	164 kg	205 kg
7,0/230	147 kg	185 kg
6,5/215, 200, 180	131 kg	165 kg
5,5/160, 150	100 kg	125 kg
5,0/150, 140, 130	85 kg	105 kg

Key:
1. Nail type, outside diameter/length [mm]
2. Allowable holding strength per nail under shear stress
3. In accordance with the formula in the SIA Standard 164 [no reduction because of round timber connections]
4. Estimated on the basis of the loading experiments of the EMPA

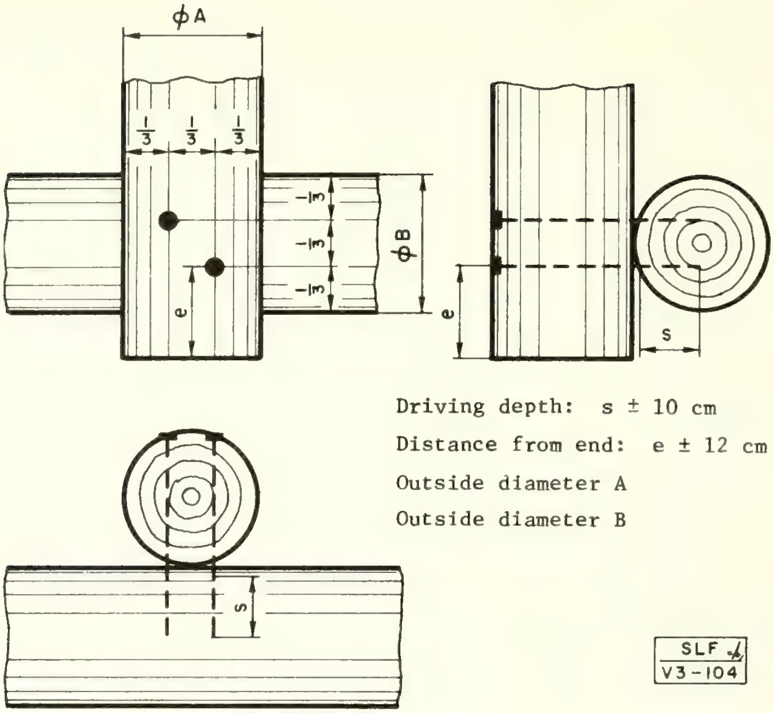
"The values underlined in this table are valid only under the assumption that the design instructions contained in Section d with regard to nail spacings, etc., have been maintained.

"c) Possible Ways of Increasing Holding Strength: There are many possible ways of increasing the holding strength of this nail fastening: preliminary drilling of the nail holes, arrangement of three instead of only two nails per connection (difficult for space reasons), flattening the contact surfaces, the use of screw bolts above 200 mm in outside diameter, the use of screw nails, etc. Of these proposals, the most valuable is that of preliminary drilling of the nail holes (drill hole diameter = about 85 percent of the nail diameter), which has the effect of increasing the holding strength about 25 percent and of substantially reducing the risk of splitting. Other proposals are in part considerably more expensive and in part involve additional difficulties. Screw nails [ring shank] possess a high resistance to extraction; the thread end of screw nails is therefore more firmly seated in the wood than is that of the conventional nail having a smooth shaft. Hence, the deformation of the nail fastening is less. However, whether the holding strength can be substantially increased is something which must be clarified by experiments of the EMPA.

"d) Carrying Out the Nailing Operations: Since the nailing of such round-timber snow rakes differs in some respects from nailings in conventional wood construction, in the following instructions are given for carrying out round-timber nailing (see also Figure 7):

"1. Nail length and driving depth: The choice of the nail type should be based not only on the tensile forces to be encountered but also should take into account the required length. According to the SIA Standards, in single shear connections, the nail point should penetrate at least 8d (d = nail diameter) into the second piece of wood. Since this recommendation is somewhat optimistic and since with round-timber nailings the risk is particularly great that in consequence of oblique nailing this limit will not be maintained, we propose, independently of the nail type: $s \geqq 10$ cm, i.e., the nail length should be at least equal to the diameter of the round timber to be nailed plus 10 cm.

"2. Nail spacings: In order to reduce the danger of splitting, we propose the end distances, intermediate distances, and boundary distances listed in the sketch.



Driving depth: s ± 10 cm
Distance from end: e ± 12 cm
Outside diameter A
Outside diameter B

Figure 7. The nailing of round-timber snow rakes (after H. Straessler).

"3. Driving the nails: The nails are to be driven straight, i.e., perpendicular to the plane of the grid. This reduces the danger of splitting (the nails do not travel in a precisely radial direction and avoid any shrinkage cracks which may already be present) and the proposed standard measurements for end spacings, driving depths, are more likely to be guaranteed. The nail heads should not be driven into the wood; drive to the point of contact between the underside of the nail head and the surface of the wood.

"4. Nail surface: Phosphated nails should be employed; in contrast to plain nails the danger of rust is eliminated (or at least significantly reduced) and besides the extraction resistance is significantly higher."

When the nail fastenings between the grid and the main framework no longer suffice to resist the tensile force acting in the plane of the grid, the tie and stringer should be connected by a wire cable in addition to the grid nailing, as shown in the sketch contained in Figure 5. Here it should be noted that the compression stresses in the stringer and in the tie along the cable bearing must not exceed allowable transverse compression stress values, otherwise this situation should be prevented by suitably dimensioned flat steel support.

Stringer and supports are finally connected by a steel strap which is nailed to the supports on both the uphill and downhill sides.

What has been said regarding the checking of permanent supporting structures (compare W. Schwarz, Section 5), applies with appropriate changes also to temporary supporting structures. Here, in addition, it is also necessary to periodically subject the structural wood to a thorough investigation for fungus infestation. Just the external appearance alone of the wood surface -- primarily a brown to gray-black discoloration along shrinkage cracks and at cross-cut ends -- gives the wood specialist valuable indications of possible foci of rot. Often small to fairly large fungus spores can also be found on the surface of the wood and these will lead to further investigations for the presence of wood rot. Especially to be recommended is rapping on the wood with a hammer. Healthy wood gives a characteristic more or less bright sound, while zones attacked by rot are recognizable by their dull sound. In doubtful cases, boring samples provide direct information regarding the local condition of the wood. (Drill holes should be impregnated after removal of the sample and should be closed with a treated wood plug.) Also, the wood which is built into the ground should be included in these investigations at least at intervals of several years, taking samples by laying bare parts of the wood. Only by means of repeated field tests of this sort will one's attention be drawn to the particularly endangered structural portions of supporting structures and will one be in a position either to carry out suitable wood protective treatments before it is too late or to replace wood which has been weakened by rot before the entire structure collapses under the snow burden. Checks and maintenance operations carried out consistently and in a technically correct manner contribute substantially to an increase in the useful life of wood structures; they belong in the list of duties of the responsible agencies.

For data regarding the costs of the round-timber snow rake (type SLF) we can for the present only base our judgment on the Stillberg experimental project which is currently in progress. The type of structure used there, with a tie built into the ground and a structure height of 3.4 m, came to 304 Swiss francs per running meter of completed construction in 1971 (including material, transport, labor, shut-down times [Wegzeiten], building supervision). The material costs were 22 percent, labor costs 78 percent. All construction operations were carried out with in-house workers at a gross pay of 6.8 Swiss francs per hour. The installation costs mentioned also include the expenses of research; they are therefore to be considered relatively high and should not be taken without qualification as a guide for normal practical conditions.

1.6 Height and Arrangement of Temporary Supporting Structures

The height and arrangement of temporary supporting structures must correspond to the principles set down in the Guidelines. Thus, the same principles apply as in the case of permanent supporting structures. This is a logical consequence of the observation that the task and the action of permanent and temporary supporting structures -- with the sole exception of the shorter useful life of temporary installations -- are the same.

As in the case of permanent structures, allowance can be made for the various safety requirements of temporary supporting structures by introducing various spacings which at the same time are in accord with the Guidelines. The sharper limitation of allowable structure height in the case of end structures in wood construction (compare Figure 6 and Table 1) makes it appear advisable to build wood structures having more than 3 m of height in continuous arrangement. In this way, it is possible to reduce the number of end structures to a minimum.

1.7 Further Development of Temporary Supporting Structures

With the development of the round-timber snow rake presented here with its higher holding strength and greater durability, we are only at the beginning of properly engineered temporary supporting structures. It is now necessary to become familiar with the limits of applicability of this construction and this shall be on the one hand by means of comparative calculations assuming variable site conditions and variable wood cross-sections; and on the other hand by field sampling of various types of construction under extreme snow and ground conditions.

Special further development is required for:

a. the wood fastenings;

b. the uphill structural anchors in the required variants and for various types of soil;

c. protection of wood which is introduced into the ground.

The following coordination tasks arise:

a. the properly scheduled planning of temporary supporting structures on the part of the forest service, when necessary in conjunction with the EISLF (consultation, professional recommendations);

b. properly scheduled provision of main framework wood of suitable dimensions and varieties on the part of the forest service;

c. properly scheduled storage of standardized and impregnated main framework wood on the part of the wood protection industry and the forest service.

In order to be able to deal with this program, there is moreover a need for an assured interdisciplinary cooperation on the part of forest engineers, snow mechanicians, wood construction engineers, material testers, wood protection biologist, the wood protection industry, and the forest service. Finally, the results of these efforts in the interest of the technical development of effective and economic temporary supporting structures should be continuously communicated to all interested circles by means of publications, in courses, with consultations, as well as through education in advanced schools and schools of forestry.

2. Protection Against Gliding Snow

2.1 Introduction

Since the winter 1946/47, the EISLF has been occupied in special investigations and field experiments with the problems of snow gliding and of protection against gliding snow. The results of these studies have in part already been published [21, 22]. Therefore, we can limit ourselves here to a summary of the most essential principles governing the production of antiglide structures.

2.2 Snow Gliding and the Effects of Gliding Snow

On a smooth, inclined surface, for example, on long-bladed grass or on smooth flagstones, a snow cover having a wet lower layer can acquire a slow movement. This translation of the entire snow cover on the surface of the ground at rates ranging from millimeters to meters per day is called snow gliding (compare M. de Quervain, Section 3).

This occurs with pronounced frequency in gliding snow locations which are smooth, grassy slopes having an inclination from about 28° to 50° at elevations of about 1,200 m to 2,500 m and having an east by south to western exposure. Extreme snow gliding manifests itself in sickle-shaped glide cracks and in avalanche-like gliding snow fractures [Gleitschneerutschen]. In combatting snow gliding the primary purpose is to prevent these extreme processes. Depending upon whether the ground is frozen or unfrozen during snowfall and in the further course of development of the snow cover, the snow cover glides only on certain days or during the entire winter. Gliding snow zones can be located at slight cost simply by means of a few photographs of typical gliding snow situations -- particularly after snowfall on unfrozen ground.

Among the causes of the motion of gliding snow are:

a. the shear force which results from the weight of the snow cover and which is directed parallel to the slope down the fall-line;

b. the low frictional forces of the wet lower layer of the snow cover on a smooth foundation;

c. failure of the snow cover to bond to the ground.

Uphill of natural and artificial obstacles, snow gliding imposes a marked magnification of the practical blockage range, i.e., that zone in which substantial compressive stresses are evoked by the snow cover. The extension of this blockage range up the slope is thus equivalent to an increase in the snow pressure acting on the obstruction.

The damage caused by gliding snow to structures and vegetation in structural control projects and in afforestations can be considerable if the glide factor has been too optimistically evaluated. In addition to instances of damage to individual structures, it is possible for entire groups of supporting structures to be squeezed out together with the top soil. Forest plantings are either scraped by the friction forces of the snow gliding over them or are partially to completely torn out. The criteria for estimation of the glide factor are contained in the Guidelines [2].

2.3 Protection Against Gliding Snow

Combatting snow glide is based primarily on increasing the roughness of the ground surface and upon bonding the snow cover to the ground and vegetation cover by artificial means. In the Guidelines, it is recommended for zones having high glide factors to weigh whether an increase in roughness of the ground surface is economically preferable to the construction of stronger types of structures. In the case of the creation of temporary supporting structures having a foundation which on the uphill side is not very strong in tension (e.g., an open tie anchored with pilings) this artificial increase in roughness is elevated to the level of a prerequisite (compare Section 1.5). Similar preventive measures for the limitation of snow gliding should be carried out in the case of afforestation on gliding snow slopes.

Depending upon their mode of action, the following are the most appropriate antiglide measures:

a. increasing ground surface roughness: terracing (stepped terraces, dished terraces, planted holes);

b. an increase in ground surface roughness and, at the same time, an anchoring of the snow strata which are near the ground: pilings, antiglide structures (suitable for gliding snow regions having a tendency to wet snow fractures);

c. meshing the snow cover base with the vegetation layer: planting.

In carrying out the various antiglide measures the following important points are to be noted:

2.3.1 General Remarks

With an arrangement of the protective structures which is dense and distributed over an area, care must be taken not to exceed the allowable ground stresses and the allowable shear stresses of the snow.

On smooth slopes, antiglide structures should be constructed for slope inclinations above about 28°.

2.3.2 Stepped Terraces (Figure 8)

Breadth 30-50 cm constructed in excavation;

Stepped terrace ground inclined in the direction of the slope and constructed of sod squares which have been solidly tamped and flattened in the uphill direction, tilted laterally outward onto a rough-hewn step and built into abutments perpendicular to the fall-line;

Depending upon the water drainage conditions, the stepped terrace axes incline against natural drainage channels;

Slope distances:

Slope Inclination	Spacings
28°-35°	140-120 cm
35°-40°	120-100 cm
40°-45°	100- 80 cm

Continuous or broken arrangement with dished terraces (stepped terraces about 50 cm long having an average lateral spacing of 100 cm in a triangular formation);

Avoid recent slides and loose, rough soils;

Construction in the spring (settling, solidification up till the next winter);

Relatively low construction costs;

Reduction of the costs of nursing young vegetation (does away with the need for combatting weeds in the first years).

2.3.3 Wide Terraces (Figure 9)

Breadth 100 cm and more, built in the form of excavation and fill;

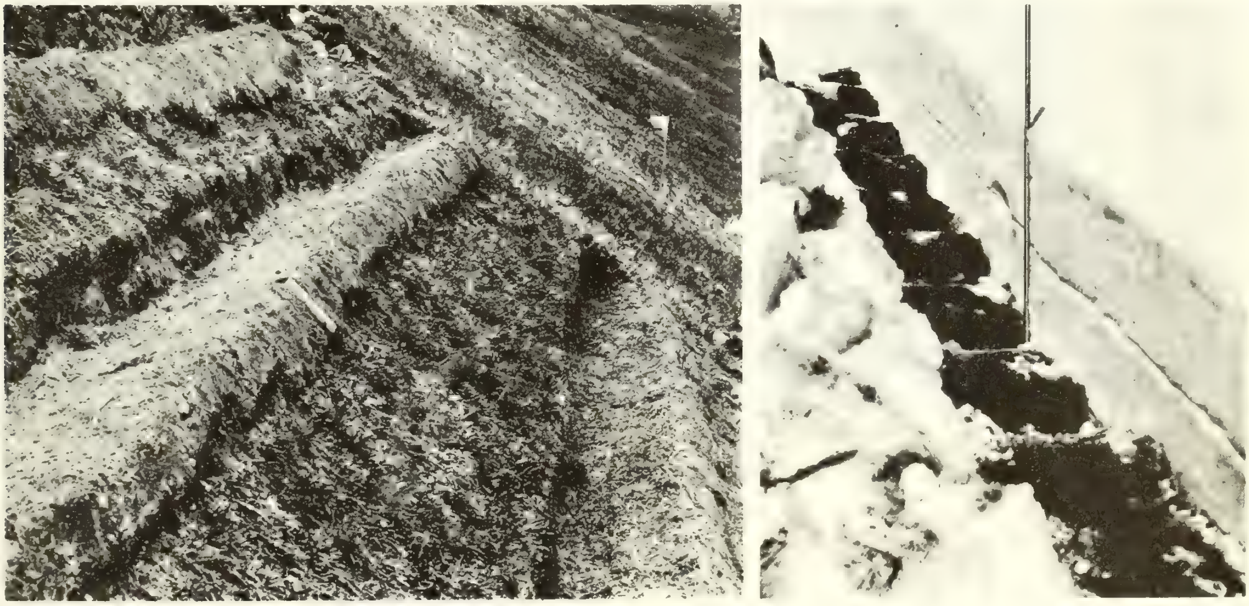


Figure 8. Left: stepped terraces, continuously arranged. Right: increase in ground surface roughness by means of stepped terraces (photos H. in der Gand).

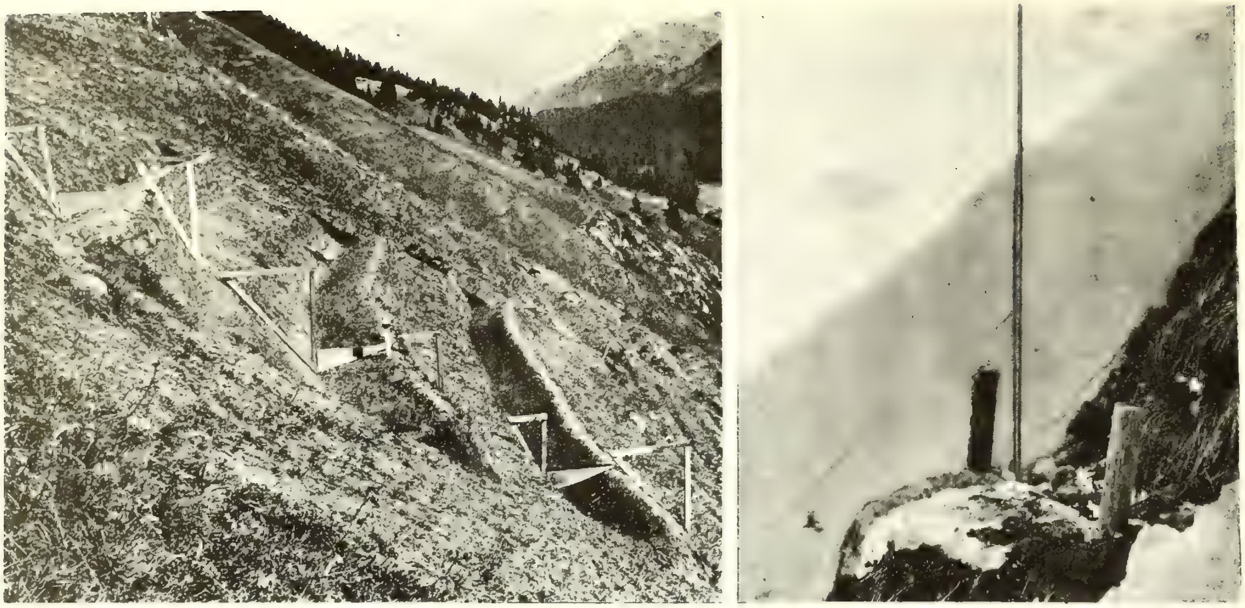


Figure 9. Left: wide terraces. Right: wide terrace with piling; deformed old fracture formation in the snow cover at the edge of the terrace (photos H. in der Gand).

Disadvantageous are the steep, long slopes of cut and fill which have the effect that slope distance becomes greater with increasing slope;

Formation of tension zones along the edges of the terraces = zones of potential glide cracks and slab avalanche fractures;

Danger of compression of the terrace embankment by the action of snow pressure;

Unsuitable on steep, snowy slopes;

Relatively high building costs;

Additional antiglide measures are required between the broad terraces.

2.3.4 Pilings (Figure 10)

Piling spacing becomes smaller with increasing slope inclination and snow depth (≦ 30°/HS 150 cm = piling spacing 200 cm, 45-50°/HS 300 cm = 90 cm; for guide values compare [21]);

Arrangement in triangular formation, possibility of plantings between the pilings (increase in ground surface roughness);

Minimum piling diameter: ● 10 cm, ◓ 16 cm, ▲ 20 cm (radius = 10 cm);

Required ratio of depth of burial to piling height above ground = 2:1;

Minimum burial depth (dependent upon snow pressure and ground strength); dense soils -- 60 cm, loose soils -- 80-100 cm;

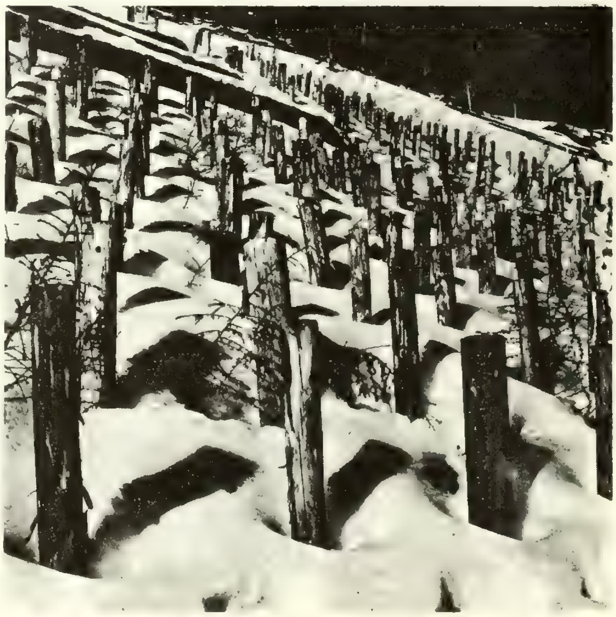


Figure 10. Pilings (photo H. in der Gand).

Minimum piling height above ground (dependent upon tendency for the formation of wet snow fractures) 30-50 cm and more.

2.3.5 Antiglide Supporting Structures (Figure 11)

Rake and tripod structures of wood (also made of other materials, in the case of permanent structures, e.g., steel, compare W. Schwarz, Section 8);

Are suitable in the case when soil depth is inadequate for structures between the supporting structures and also in regions with a tendency for the formation of wet-snow slides;

Only local action against snow gliding in the immediate neighborhood of the structures;

Snow pressure effects not substantially less than in the case of normal supporting structures;

Perpendicular structure height 1.0-1.5 m;

Structure length not greater than 3.0 m, broken arrangement (do not undercut snow cover over a long length, owing to [possible] formation of zones of tension and zones of shear = zones of potential glide cracks and slab avalanches);

Slope distance not greater than 10 m (slope inclination 37°);

Anchor uphill foundations against tensile stresses (e.g., steel pilings).

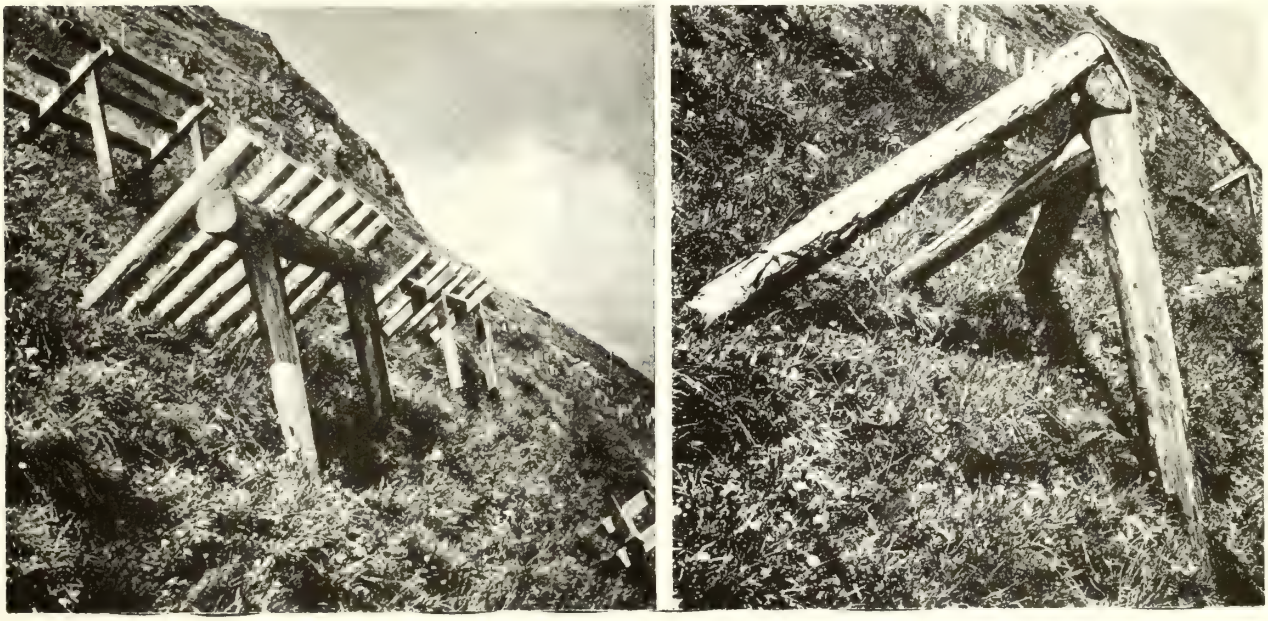


Figure 11. Left: antiglide rake of round timber. Right: antiglide tripod of round timber (photos H. in der Gand).

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English Translation of German Titles

[1] An Analysis of the Avalanche Control Structures in the Bernese Oberland.
[2] Avalanche Control Structures in the Starting Zone, Guidelines of the Federal Forest Inspectorate for Supporting Structures.
[3] Contribution to the Use of Standardized Wood Structural Designs in Avalanche Control Structures.
[4] On Properties of Poles and Round Timber Employed in Load-Carrying Structures.
[5] Material Properties of Structural Wood: Wood in Engineering and Industry.
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[10] On the Behavior of Wood and Wood Materials Under Sustained Load.
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[12] Experience and Developments in the Protection of Structural Wood.
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VIII. THE SAFETY OF SUPPORTING STRUCTURES

(Balthasar Rageth, Domat/Ems)

The almost frightening success of science and engineering has caused man to become uncritical in evaluating the limits of technology. He is easily inclined to place blind confidence in technical progress without taking further thought. In broad segments of the population, the view is prevalent that avalanche structures in the starting zone offer absolute protection.

It is the purpose of the following study to review the reliability of supporting structures and to explain the difficulties which beset the goal of absolute avalanche protection.

The task of supporting structures consists of preventing the occurrence of avalanches in the construction region, or at least to arrest or retard snow movements which do arise, so that no damaging effects need be feared (compare B. Salm, Section 4.1). This formulation [1] already contains the observation that absolute protection of starting zones is not attainable. Absolute safety means the exclusion of any possible risk even in situations of extraordinary danger (compare W. Schwarz, Section 2).

Snow is not a homogeneous substance. Its properties change with time and place and its behavior under the influence of external forces is subject to great changes. This is the primary source of the difficulties involved in computationally interpreting the self-willed and complex reactions of a mass of snow and of developing suitable protective measures to prevent damage produced by moving snow (compare B. Salm, Section 2).

The use of articulated supporting structures began in the early 1950's. Since then, almost everywhere preference has been given to this system as opposed to the traditional massive construction (walls, etc.). If now it is a question of evaluating the suitability and the effectiveness of these modern construction methods, then at the outset we can be gratified that the great majority of supporting structures have provided the protection expected. One can hardly imagine the damage and devastation that would have occurred in the alpine area without control structures and which would occur in future. Nevertheless, one may not ignore the fact that, on the one hand, avalanches have also descended into constructed regions and, on the other hand, the resistance of the installations with respect to the effective snow forces has in part been inadequate. Likewise, the reliability tests which have existed up to now may be only conditionally taken as a guarantee of the protective effect of our structures against future catastrophic situations of an unpredictable magnitude.

But it would be completely unrealistic to place in doubt the fitness of supporting structures because of occasionally observed deficiencies in individual projects or parts of projects. There will always be reverses. We should not be disheartened by negative individual occurrences, but should be spurred on to increased efforts to eliminate still-existing inadequacies.

Since the beginning of avalanche construction in the second half of the 19th century, this principle has been steadily adhered to. In the thirties, science had begun to concern itself intensively with research into principles. Since then, an active and gratifying cooperation between research and practice has prevailed. After its first edition in the year 1955, the "Guidelines for Permanent Supporting Structures" [1] was revised in 1956, 1959, and 1961. Each revision brought a sharpening of definitions both with respect to structure design and also with respect to the specifications governing projects. The last revision, which in addition also covers temporary supporting structures, is dated 1968. This rapid succession of changes in the Guidelines implies that the initial expectations regarding the effect of supporting structures have not been in all respects satisfied. On the other hand, they testify to the continual efforts to usefully apply the new knowledge and the experience which has been acquired. The sharpening of the Guidelines also indicates that projects carried out in recent years -- assuming the installation arrangements to have been in accordance with the Guidelines -- have attained a higher level of safety than have earlier projects.

Science has achieved significant progress in penetrating the mysteries of snow. Here pioneer work has been accomplished by our

Federal Institute for Snow and Avalanche Research in Weissfluhjoch-Davos. But there still remains much to do. Research is still far from the end of its far-ranging task.

The task of the practical avalanche engineer consists of referring acquired general experience and new knowledge to a specific individual object and there to apply it appropriately. As the subsequent commentary will attempt to show, this is not an easy undertaking.

Natural conditions in winter terrain are extremely manysided. Every site is distinguished by its own special character which manifests itself in conjunction with a number of individual factors and which depends upon elevation, slope inclination, exposure, snow depth, nature of the soil (rock, coarse gravel, earth, smooth or rough surface), topography (sharp crest, broad crest, couloir, ravine, uniform slope, etc.), slope changes above and below the installation site, effect of wind upon snow distribution, ground covering (forest, grass), etc. Should we be surprised that in structural control of avalanches, one must be content with Guidelines, i.e., with instructions which often have wide variability?

The determination of the combined effect of the local factors with regard to processes in the snow cover and the inference from these, by using the Guidelines, of correct conclusions for determining the position and size of installations is the most important and most difficult task of the practitioner. The achievement, in a project, of a level of safety corresponding to requirements is largely identical with the capacity of the planner to recognize avalanche starting zones and to delimit them and to determine the winter conditions prevailing at the site. The determination of avalanche starting zones in winter is not always guaranteed. It is true that after the descent of an avalanche the contours of the fracture lines are still recognizable. But avalanches frequently occur in bad weather. The fractures, especially those of dry, high-altitude avalanches leaving few marked traces in the starting zone, are obliterated by new snowfalls or snow movements so that the course of the fracture lines can be reconstructed at best only in certain places or not at all. This work requires reliable observations, imagination, and a deep knowledge of the processes of winter. The spooky notion of "God sight" which is still occasionally encountered among foresters must finally be banned from avalanche structural control.

One of the critical decisions of the practitioner is the choice of the structure spacings down the fall-line (compare B. Salm, Section 4.2). This determines structure density. With increasing density, the effectiveness of the project increases. The Guidelines leave relatively great latitude in the determination of spacing. The great range of allowable structure spacing permits the planner to design the project to given conditions. The allowed latitude is, however, to be used exclusively for the purpose of fitting structure spacings to the safety requirement of the project. High requirements are imposed for example by the protection of inhabited settlements and hence this calls for structure spacings which are near the lower limit of tolerance. However, this latitude does not mean a concession with respect to construction density for economic reasons. It is not permissible to accept large structure spacings in order to make a control project financially more palatable. Admittedly, larger structure spacings within the framework of the Guidelines provide a theoretical guarantee of the security of the project but produce only a reduction in security against the onset of avalanches. For small projects this requirement -- because it is economically tolerable -- introduces no problems. On the other hand, in the case of large projects, it is often not so easy for the forest engineer, educated as he is to thrift, not to be impressed by high costs. If there is no readiness to subordinate the resources to be employed to the required safety specifications, then the use of supporting structures has failed at the outset.

Especially difficult is the determination of structure heights (compare B. Salm, Section 4.2). Even in the case of extreme snow depths, the support surfaces must reach to the surface of the snow. Snow-covered structures lose their effectiveness and in addition can be overstressed. New snowfalls cannot be sustained by covered structures. It is possible for avalanches to break loose which trigger larger masses of snow below the controlled area. Besides there exists the danger of damaging or even destroying the structures since the latter are not designed for avalanche forces. Meteorology provides a general reference point for determining structure heights which provides us with large-scale area averages of extreme snow depths. However, for the determination of decisive snow depth peaks at the structure site these data are not sufficient. It is also practically never possible to determine from direct measurement at the structure site the highest values of the decisive snow depths -- which on the average occur only once in about 30 years. There remains no other way than the evaluation of extreme snow conditions on the basis of intensive personal observations during several arbitrary winters and on the basis of conclusions drawn with the help of analogy on the basis of the Guidelines [1]. The snow depths are usually measured at representative locations by means of simple snow measuring rods. Zingg [4], using topographic photographs at a scale of 1:2,000, carried out photogrammetrically before and after the snowfall, was able to determine snow depths to an accuracy of 20 cm over an area of 8 hectares. At least for projects having the highest safety requirements and in difficult terrain, this admittedly expensive method of determining the mass distribution of the snow cover in low relief should be given consideration.

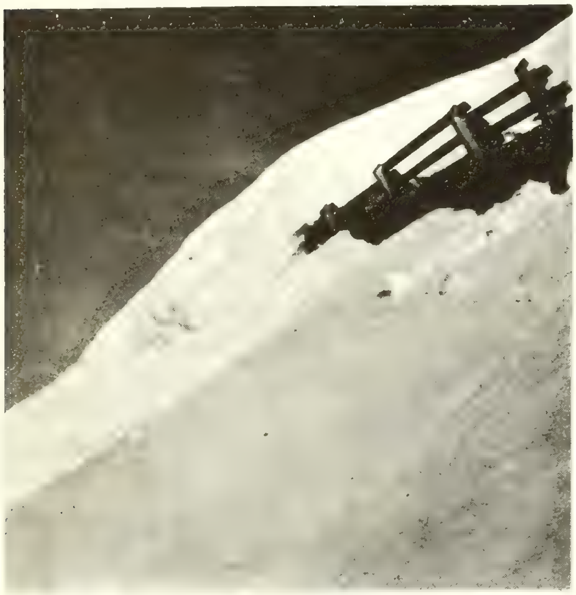

Figure 1. Supporting structure partially covered by wind action (photo H. Fluetsch).

The effect of wind on snow distribution renders the determination of structure heights difficult. It causes considerable modifications in the deposit of snow. Ditches, ravines, flat places, hollows, are often filled in immediately after the first snowfall, while humps, peaks, and ridges often have little or no snow until spring. Therefore, it is essential for the avalanche engineer to know the prevailing winds and their direction and strength.

When in regions acutely threatened by avalanche fractures there appear accumulations of snow which are not penetrated by the largest conventional supporting structures (for snow depths above about 5.5 m), the effectiveness of supporting structures becomes problematical. In appropriate terrain, however, there remains the possibility of smoothing out the snow deposit by artificially controlling wind flow by means of drift structures, thus keeping the snow in less endangered sections of terrain or guiding it into such sections (compare Ed. Campell, Article 9). In the Tanngrindel/Brienz project, W. Schwarz [3], using wind guidance techniques, was able to relieve the uppermost part of the starting zone of 10,000 m^3 of drifted snow, thus meeting the prerequisites for supporting structures. By increased use of wind barriers as a supplement to supporting structures, the protective effect of the latter can in many cases be increased at slight expense.

Slopes having a range of inclination between 30° and 50° are considered to be suitable for structural control (compare B. Salm, Section 4.2). Slopes below 30° are normally not controlled by structures. Similarly, one usually avoids structures on unusually steep slopes (above 45° to 50°), because during snowfalls the latter continually unload in small, undamaging quantities having the shape of a small snow slide. The problem arises at the foot of such readily unloaded terrain rises where suitably large structures are necessary to take up the additional snow sliding down from [such steep slopes]. Continuous slope discharges can cause a premature back-filling of structures and perceptibly interfere with their operation. The snow volume of long, excessively steep slopes can soon reach dimensions which can no longer be sustained by structures at the foot of the slope and which also fill in the back of lower-lying structures with loose snow slides. The quantitative evaluation of these processes is difficult. Wrong judgments with respect to the effectiveness of entire projects can give rise to fatal effects. The difficulties are increased further when the danger of rock impact exists or when steep slopes contain strips possessing the capacity to restrain the snow, producing snow masses which once in motion constitute hardly soluble problems.

Wherever possible, supporting structures should be laid out in closed terrain chambers having natural boundaries. When the lateral boundary lines have open flanks, it is possible for ground avalanches or surface avalanches to invade the controlled zones by lateral extension. Besides we must bear in mind that the avalanche paths can deviate from the fall-line. Also, without special risk to the project boundaries through influences from outside, as a consequence of creep and gliding of the snow cover substantial boundary forces occur which make it desirable to strengthen the boundary structures (compare W. Schwarz, Section 7).

In addition to the design of the structural elements in accordance with the Guidelines, ground anchoring conditions are also of decisive importance in guaranteeing the rigidity of the structures. The uphill beam foundations and the downhill support foundations must in design and magnitude be adapted to the resistance offered by the ground. No difficulties are created by compact easily anchored rocky soil. Soils which are formed by permeable rock fragments are relatively free of problems, for example, deposits of rock originating from rock falls or glacial sediments. Poor foundation prospects are offered by rocks which absorb considerable quantities of water without releasing them, such as clayey rock or lime-containing rock, weathered shale, etc. In the case of soils having low carrying capacity, the upper and lower block foundations must be tightly bound together by a compression bar which has good bending rigidity so that foundation and superstructure form a closed framework. Under unfavorable conditions, the foundation cost can attain as much as 50 percent of the [total] cost of the structure. Standardized compression tests [1], carried out in conjunction with ramming probes, give aid in determining the allowable soil compression and thus assist in designing the foundations. Hitherto too little use has been made of this in practice. In the first years after the avalanche winter of 1951, inadmissible attempts were made in many cases to effect savings in designing the foundations. Individually, these weakly designed foundations were not able to withstand extreme snow pressures (gliding snow, larger snow slides, breaks in snow drifts).

Here attention must be given to another difficult problem. As a rule, only the uppermost starting zones of avalanches are visible. If structural control is applied here, then more low-lying, previously unrecognized, secondary starting zones can appear. When such conditions exist, protection of the visible starting zones by means of structures probably reduces the frequency of avalanche descents, shortens the avalanche path, and reduces the quantity of snow in motion (compare B. Salm, Section 3). But there still remains a danger which at best has been merely diminished. These circumstances, often difficult to recognize, must be dealt with by determining the lower boundary of the control area (compare B. Salm, Section 4.2).

In all larger projects, particularly in those which are technically difficult, one encounters construction sites which are good and some which are not so good. As a rule, possible weak portions can be recognized, after completion of the project, by continuous observation and can be eliminated. In this way it is possible to still achieve, by the use of supplementary measures, a degree of safety

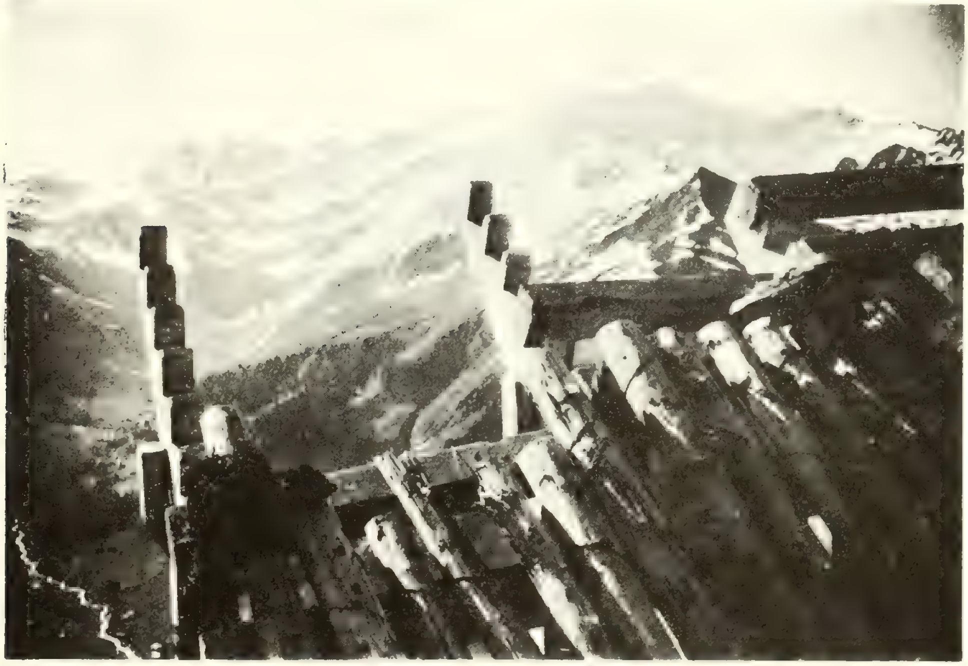

Figure 2. Structure damaged by a snow slide including rock impact; good effect of the wooden protective grid is discernible (photo A. Graemiger).

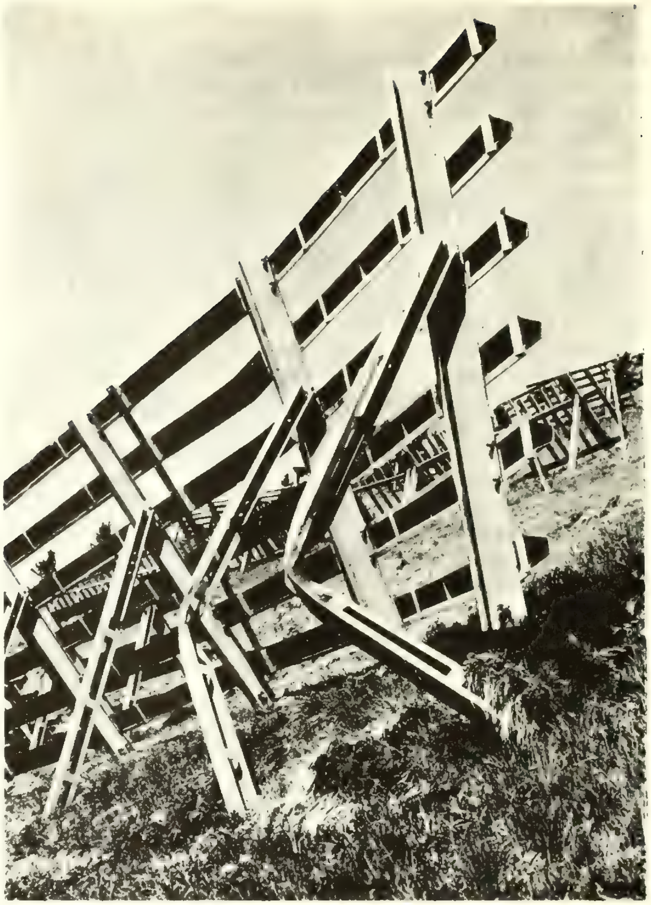

Figure 3. Buckled supports of an end [boundary] structure following marked gliding of the snow cover (photo H. Frutiger).

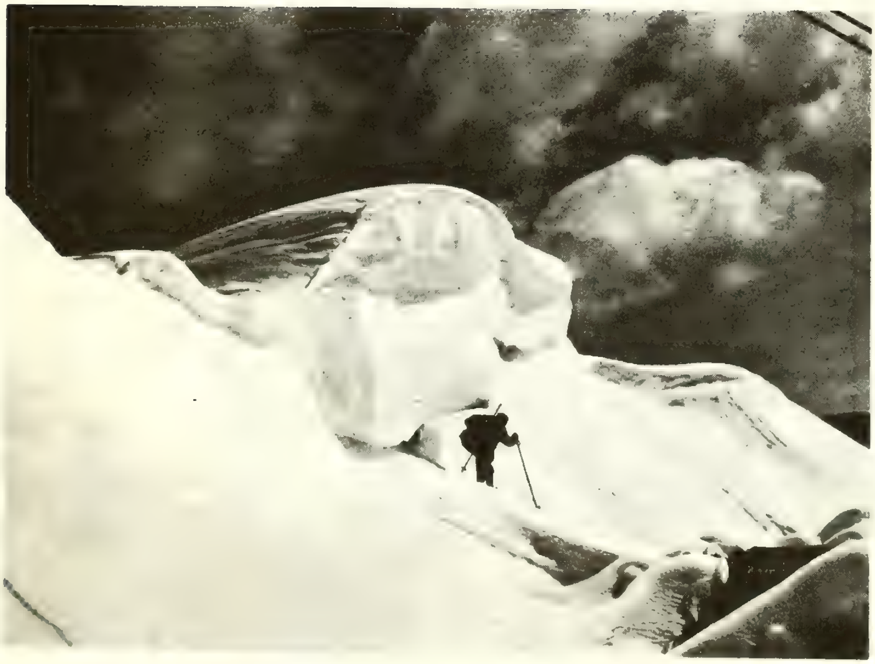

Figure 4. Cornice formation on a ridge crest (photo R. Gerber).

which had been sought at the outset but not attained on the first attempt. The necessity of supplementary credits is frequently to be attributed to this circumstance.

Finally, as reliable an evaluation as possible of the site is to be sought for reasons of cost. On a uniform slope of 45° and 1 hectare in extent one will require, depending upon the circumstances, 600 to 800 m of supporting structures. On the average for the full control of 1 hectare of average difficulty from 500,000 to 600,000 francs must be spent. Hence we have every reason to employ wisely and thriftily the means placed at our disposal so abundantly by the public. Thrift means the best possible determination of the local conditions, the most appropriate delimitation of the control region, and the correct choice of structures and of structure sites. Thrift means, further, good organization, cost comparisons of equivalent structure types, appropriate subcontracting, good raw material purchasing, and expert construction supervision. But thrift never means skimpy design, poor quality, or making concessions with regard to what we know to be the correct structure density. Previous experience has made abundantly clear that when dealing with avalanche construction, this type of saving is not appropriate.

The safety achieved by the project must remain for many decades or even forever. A continuous check of the state of the project is therefore indispensable. Damaged locations must be immediately corrected and any detected deficiencies removed. Negligences in maintenance produce losses of safety which must lead to unpleasant consequences. Hence permanent maintenance of the structures is a prerequisite for guaranteeing undiminished project effectiveness. A damaged control area is more dangerous than an unconstructed slope because the threatened population is lulled by a false sense of security. Maintenance and repair operations, when damage occurs, require considerable expense. We shall find that as the project ages, these expenses will increase. The districts will not be in a position to make the necessary funds available. One day a point will be reached at which both the Federal Government and the cantons will also make contributions to the maintenance of structures. These repair problems, which emerge only later on, and are not to be underestimated, must be thought about even in the planning stage. The better the problems of material transport can be dealt with, the easier and more economical maintenance will be. Hence, it is probable that, looking ahead, in avalanche construction projects of some extent, the installation of construction roads may be preferable to the use of temporary cable cars or helicopter transport, as long as the road-building costs lie in an acceptable range.

From the preceding remarks it should not be difficult to see that the remaining residual risk of supporting structures cannot be expressed in numbers and percentages. In winters having normal snow conditions, the protective effect may be described as safe. But we build primarily for extraordinary catastrophic situations and for this case -- as mentioned at the outset -- absolute protection is not fully guaranteed. Practically, this reservation means

a. that people below structurally controlled regions in times of danger should adapt themselves, by suitable behavior, to the existing residual risk (e.g., temporary avoidance of travel in the town, occupancy of suitable rooms such as cellars, and evacuations when necessary) and

b. that when supporting structures are installed, the avalanche endangered regions lying below it (red zones) can as a rule be converted at best into regions of reduced avalanche danger (blue zone) but not into avalanche-safe regions (white zones).

Nevertheless, supporting structures attack the problem at its root and in comparison with all other measures of structural avalanche control, it offers advantages which make it appear to be the best solution in most cases. But whenever the nature of the terrain in the starting zone presents excessive technical difficulties and the possibility of a technically satisfactory supporting structure in accordance with the Guidelines is doubtful, or whenever projects using supporting structures gives rise to unwarranted costs in proportion to the significance of the object to be protected, the idea of supporting structures is then out of the question. As a rule, a way out can be found by means of other construction alternatives.

Many will find it a disappointing admission to concede that supporting structures do not provide absolute safety. Steep winter slopes cannot be compressed into mathematically exact formulas. One may double or otherwise multiply the expense, but the fact still remains that a residual risk remains. This is a fact which we must learn to live with.

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English Translation of German Titles

[1] Avalanche Control Structures in the Starting Zone, Guidelines of the Federal Forest Inspectorate for Supporting Structures.

[2] Avalanche Control Structures in the Starting Zone, Commentary on the February 1961 Guidelines for Permanent Supporting Structures.

[3] The Limits of Modern Avalanche Control Structures in the Starting Zone.

[4] The Determination of Snow Depth Distribution Photogrammetrically.

IX. SNOWDRIFT STRUCTURES (Eduard Campell, Bever)

1. Foreword

Experienced avalanche engineers who are active today in preventing avalanches would be in a distinctly better position to write this article than I am. Indeed, no one would wish to expose himself to the criticism which such an empirically founded type of construction must expect. The following discussion is based upon data in the literature, reports of forestry officials who supervised control projects, and upon my own observations.

While gliding snow protection and supporting structures on an avalanche slope attempt to prevent just about any sort of motion of the snow cover, it is the aim of snowdrift structures to influence snow masses which are put in motion by the wind.

2. Effect of the Wind Upon the Snow Cover

When wind is completely absent, snowflakes fall as light structures made up of a variety of snow crystals which adhere to one another and which, at low temperatures, form a loose snow layer. In a protracted snowfall, such deposits can lead to outbreaks of wild snow. In the higher elevations above timberline, this phenomenon is a great rarety. At that elevation the wind is more the rule than the exception. The wind quickly tosses the snow crystals into the air, deforms them, and combines them into dense flakes. All snow is more or less blown about either while falling or subsequently on the ground, much like blown sand in the desert (Figure 1). We call the wind-blown snow drifted snow (Figure 2). The nonuniform distribution of the snow cover is a typical phenomenon of irregular terrain in the mountain landscape. In the very first snowfall, ravines, hollows, and flat parts are covered over while crests, elevated peaks, and ridges are swept clear. The terrain profile is progressively leveled off by the snow.

In order for the wind to attain sufficient shear force, a minimum wind velocity is required which, depending upon the climate and the nature of the snow, varies between 3 and 7 m/s [15]. In dry climates and on slopes, snow drifting can start even at a reduced wind velocity. Freshly fallen dry snow is naturally more easily blown than wet snow and old snow.

Snow particles deformed by the wind are hurled together and densely deposited without intermediate spaces. Thus there arises a layer of compressed snow which becomes deeper. If the foundation of this new consolidated snow cover consists of old snow which either has been or is being loosened by frost and metamorphism, this gives rise to the so-called slab. The latter usually has only slight bonding to its foundation. A slight overload or shock can cause the foundation to slump and the snow slab situated on a slope to begin sliding.

Over crests and gradient breaks the wind sweeps the snow away. An eddy arises and individual snow particles are plastered in the form of compressed snow against the edge of the gradient break and this in time produces a cornice while the remainder of the drifted snow is deposited in the form of loose snow on the lower lying lee slope.

3. Wind-Control Structures Along Traffic Arteries

On the relatively flat terrain of valley floors and on mountain-pass roads, drifting impedes traffic. Railway facilities have been protected from drifts by means of galleries, jet walls, snow walls, etc. Along highways, depending upon the region and snow conditions, fences, lattices, nets, etc., have been set up in various designs and tested. In our area, we use the Graubuenden type snowfence which can be repositioned when necessary. The investigations of Croce [4] and T. R. Schneider [15] have led to the following conclusions: continuous fence installations having a density of 50 percent and a fence-to-ground gap of at most 15-20 cm have proven best. These installations should wherever possible be set up perpendicular to the main wind direction. A maximum deviation of 20^o is allowable. Wide boards reduce the effectiveness of the fences. For a 50 percent density, a slat width of 5 cm should not be exceeded. For the distance of the fence from the road which is to be protected from drifts, a standard of 15 times the fence height is assumed. When a second fence is put up in the rear, this is placed at a distance which is 10 times the fence height. In level terrain, Croce set up the following formula for the

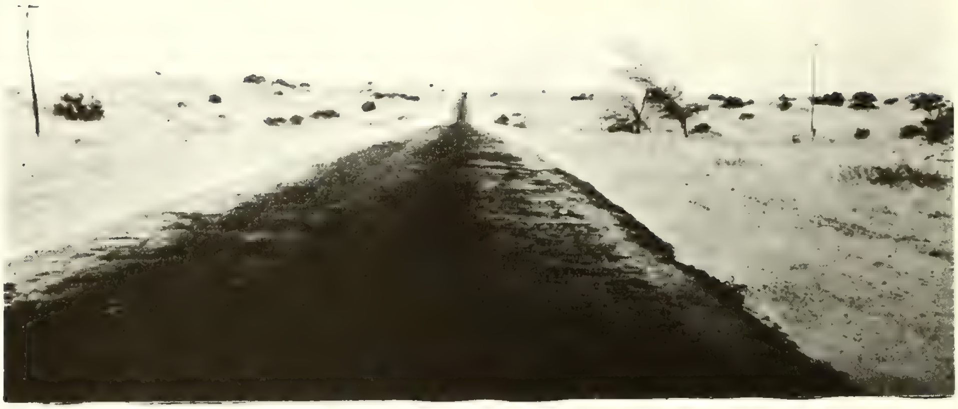


Figure 1. Blown sand desert along the Peruvian "Pan-American Highway" near Piura, 5° latitude South, 12 May 1966 (photo Ed. Campell).

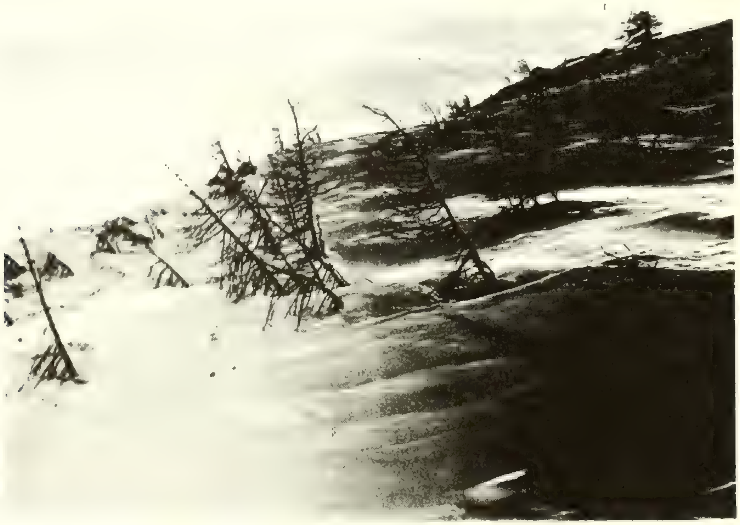


Figure 2. Drifted snow on the "Pru dal Vent" at Alp Gruem, 15 March 1934 (photo Ed. Campell).

distance from the wind barrier to the object to be protected

$$A = \frac{11 \cdot 5h}{k} + 5$$

where A is the distance and h is the height of the barrier and k is a factor which varies between 0.8 and 1.35 depending upon fence density, which is assumed to be between 35 percent and 75 percent.

4. Snowdrift Structures in the Structural Control of Avalanches

Even in the oldest avalanche control projects, the action of the wind has been utilized, perhaps unintentionally. The construction of short, staggered, dry walls indicates a recognition of this principle. The more sharp wall-corners there are, the more snow deposition is disturbed. As far back as the thirties, in the Schafberg project at Pontresina at an elevation of over 2,600 m, we achieved good results by erecting angular, elevated wall-wings and high individual elements in place of rounded wall-flanks. In old avalanche projects, we often encounter in the slope direction or above the starting zone in predominantly flat parts of the terrain so-called cornice walls. Because of the unsuitable nature of the stone, the installations could usually not be built high enough so they became prematurely drifted-in and ineffectual. In order to deal with these disadvantages, compact wooden walls and wooden rakes have been set up but these did not produce the success which had been hoped for (Figure 7, profile 4). E. Eugster [5] in the thirties was the first in Switzerland to investigate and describe various types of wind barriers in the upper Valais. Here he established that snowdrift structures as a means of restraining snow, in addition to preventing cornices, merited close attention, especially in unobstructed terrain and above timberline, as a supplement to supporting structures.

When after the avalanche winter of 1951 there began a new period of avalanche defense construction and articulated supporting structures came into general use, the practitioner also became increasingly interested in snowdrift structures. In a certain respect, the articulated type of structure itself exerted significant influence on the drifted snow and hence unintentionally stimulated the development of snowdrift structures.

But it became continually more evident that as a result of snow drifting certain upper limits are set to the design of supporting structures in the starting zone [17]. Supporting structures are often overloaded and the costs of stronger and higher structures exceed an acceptable size. Also the underlying soil is often no longer adapted to carrying heavy loads [11]. This circumstance has contributed to putting a brake on the real culprit, the wind, or to the utilization of its forces in snowdrift structures.

Depending upon the purpose and the mode of action, the following two types of snowdrift facilities may be distinguished. Different types of barriers have developed for each:

a. Structures which hinder the transport of drifted snow, slow the wind, and produce a deposition of the transported snow before the latter is deposited excessively in the starting zones of avalanches. These include snowfences with horizontal slats [Treibschneehag], and snowfences with perpendicular slats [Treibschneezaun].

b. Structures which promote the transport of drifted snow, which deflect the wind in such a way that the drifted snow is continually swept away from certain avalanche starting zones or in such a way that the wind turbulence disturbs the normal build-up of the snow cover. These structures include the jet roofs, drift-snow ramp [Pupitre or Pultdach], and Kolktafeln [eddy panel].

4.1 Structures Which Weaken the Shear Force of the Wind

The design of these structures is based on the principle of the porous wall. Instead of filling them out completely, gaps are left between the boards or planks. The drifted snow is blown through the gaps. Wind velocity is reduced and thereby its carrying capacity is weakened. The greater the density of the obstruction, the more quickly will the drifted snow fall out. On the other hand, the density must be so selected that the snow masses deposited on the leeward side of the barrier are deposited at the desired location without, influencing the function of the barrier. The height of the latter is determined by the quantity of drifted snow which must be held back at the site. By increasing the height of the structure the duration of its effectiveness can be prolonged into late winter [17]. Fences staggered one behind the other considerably increase the amount of drift snow caught.

The simplest design for a snowfence with horizontal slats has been used (Figure 3) by A. Graemiger on Hubel-Tschatschuggen on the Kueenihorn in St. Antoenien (Figure 3). The boards are fastened horizontally to the lee side of 3-4-m-high posts, with a density ranging from 50 to 60 percent. For safety, the posts are braced on the lee side with supports. The amazing effectiveness on the lee side of the ridge of this simple fence is apparent in Figure 4. Over the entire length of the windward side of the fence cornices have almost been completely eliminated. Here only a slight steepening is visible in place of a cornice. On the left side of the picture one can see exactly where the effect of the fence ceases and a large cornice has been able to develop which in fact led to the fall of the cornice.

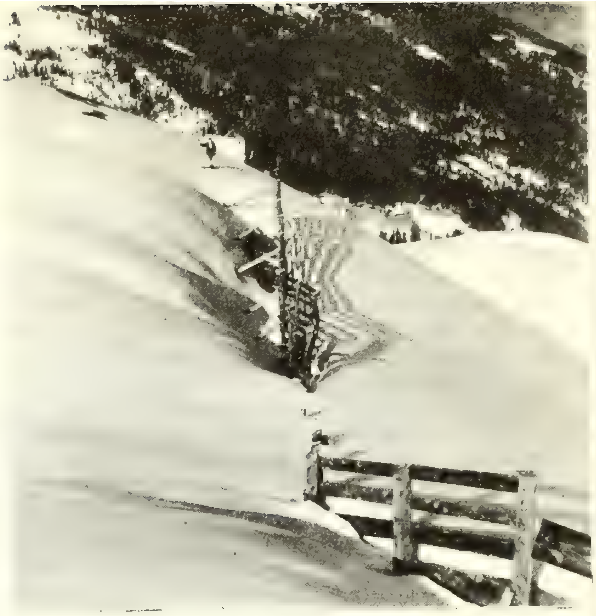


Figure 3. Effect of the horizontal board snowfence on the windward side of the "Hubel Ridge" on the Kueenihorn above St. Antoenien, 15 May 1970. The middle of the snowfence was drifted over in the winter of 1969/70. According to A. Graemiger fence height should have been increased there (photo A. Graemiger).

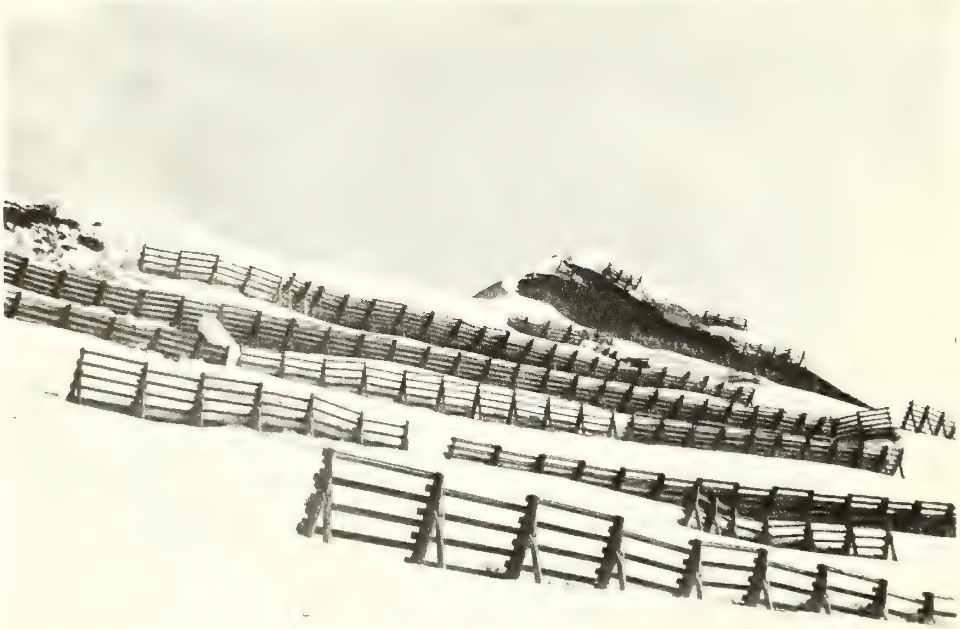


Figure 4. The effect of the horizontal board snowfence (Figure 3) on the lee slope is clearly apparent in the middle of the picture. Instead of a cornice only a short steepening has formed here (photo A. Graemiger).

Here our Tessin colleague Solari would probably say: "By all means don't build up too much snow in starting zones."

At high elevations in the dry zones of our country where there are strong winds on the slopes, good results have been obtained (Figure 5) with both types of snowfences when the slats are attached to alternate sides of the posts. Wind turbulence is amplified by this arrangement of the boards. This system was developed by J. Hopf and J. Bernard [8] in

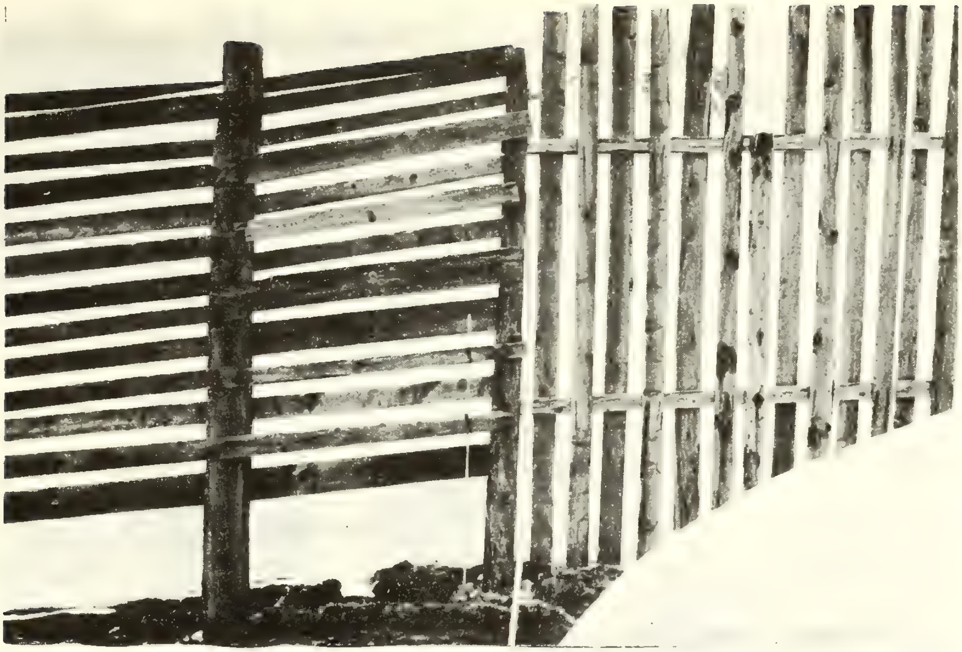


Figure 5. Construction of a horizontal board snowfence (left) and of a vertical board fence (right) in "Pluetschessa," Ftan, with boards on alternate sides of the posts (photo H. Frutiger).

the avalanche control project at Paida in Sellraintal. N. Luzzi [11] was the first to employ this type of barrier in an extensive snowfence project on the Greala High Plateau (2,500 m above sea level), above the supporting structures of the wet-soil Pluetschessa slope of Ftan (Figure 6). Fence heights were 4 m and there was a total of 1,034 m of structures. The posts have a spacing of 2 m, and are buried 1 m in the ground. The boards of the wind screen are 25 mm thick and are on the average 16 cm wide. The density averages 67 percent. For snowfences with horizontal boards, the fence-to-ground gap is 80 cm. For the fences with vertical boards, the boards extend to the ground. The latter type is more effective and is easier to maintain because it doesn't suffer from snow creep. At a slope gradient of 10 percent, it was possible to obtain a mean maximum deposition length of 40 m. The holding capability per running meter of fence [normally] varies from 90 to 170 m^3, but can reach 220 m^3 (Figure 7, profile 3). When we consider that these snow masses before installation of the wind baffles were swept entirely into the steep slope, we can get an idea of the enormous load relief which has been achieved for the supporting structures built on wet ground. N. Luzzi is firmly convinced that the Pluetschessa avalanche project would have been purposeless without wind baffles. The horizontal board snowfences of the avalanche control project in Munt Baselgia, Zernez, and Munt da Lue are carried out in the same design. In the "Val Guestina" avalanche control project above Sent (2,700 m above sea level) this system is combined with Kolktafeln in an arrangement similar to that used for up-slope wind on the Kueenihorn, and has achieved the best results.

Snowfences made of steel elements of the OeAM and aluminum fences of the AIAG have been successfully erected in various avalanche control projects in the Bernese highlands [17] and in the Valais. The aerial photograph of the snow restraining installations above Adelboden (Figure 8) and profile 1 in Figure 7 from the Tanngrindel avalanche control project in Brienz, together with Figures 9 and 10 and the profile from the Valais (Figure 7, profile 2) will allow us to dispense with further descriptions.

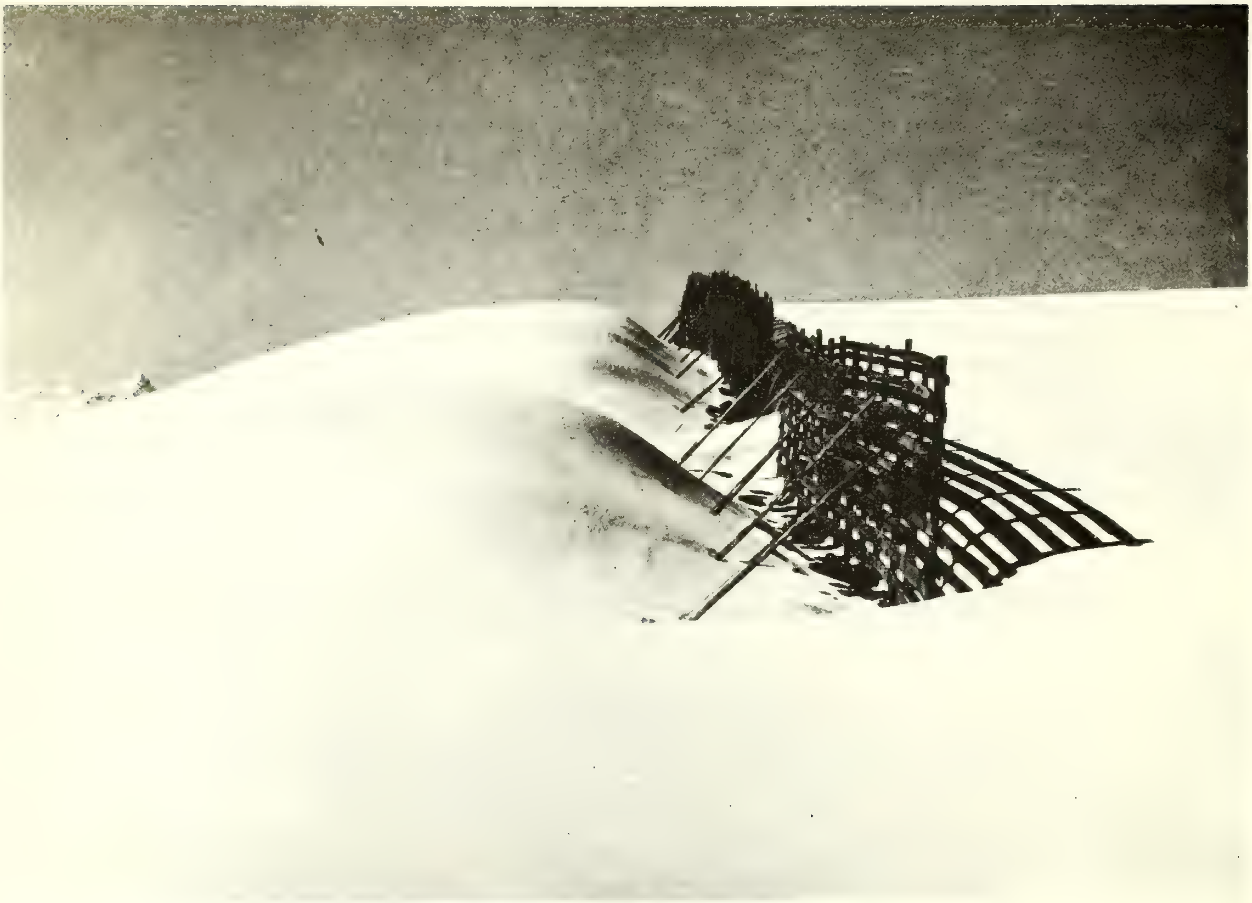


Figure 6. Snow-drift structures on the Greala Plateau (2,500 m), above the Pluetschessa supporting structures, 8 April 1960 (photo H. Frutiger).

Also, W. Schwarz is of the opinion that long fences are more advantageous than short staggered arrangements. He closed any gaps which occurred by using snow bridges made of OeAM elements having a high density. Generally, wind structures supplement supporting structures, but in this case, it is the other way around.

A principal feature of definitive snowdrift barriers is constituted by the stability of the structures against extreme wind stresses. Transverse anchoring of the individual posts using wire cable has turned out badly because the cables are so heavily stressed by snow creep that the fences are damaged or torn down. Instead of transverse anchoring, the posts can also be secured by continuous cables stressed in the longitudinal direction. For this purpose the posts, instead of being in straight line, should be placed along the outline of a flat hyperbola. In this way, each post is uniformly stressed in tension on the lee side support or brace. The installation is also secured against storm winds from the opposite direction. Such a 50-m-long, 5-m-high, woven-wire fence has been standing for 36 years undamaged and without any maintenance on the storm-swept south ridge of the Crasta Mora above Bever. In setting up lasting installations, one must also reckon with permafrost. In the Engadine, this is encountered on the south slope at 2,600 m; on the shady north slope, it can be encountered below 2,200 m.

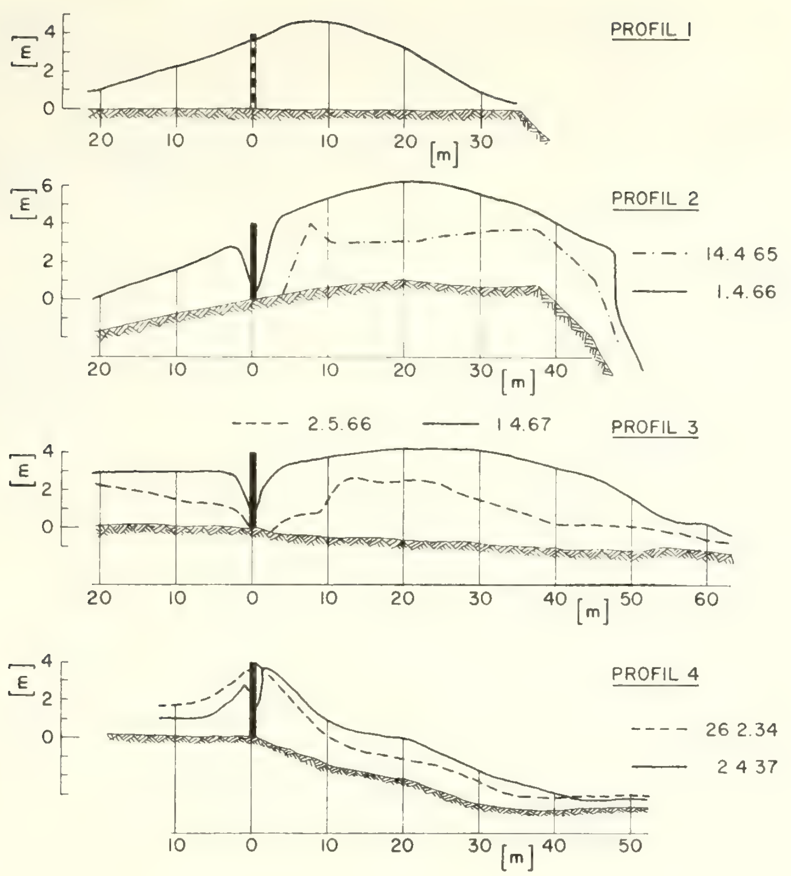


Figure 7. Cross-sections through drift snow trapping structures.

Profile 1: mean trapping capacity of a horizontal element snowfence made of steel elements in the Tanngrindel, 14 April 1964 (field data and drawing by W. Schwarz, Interlaken).

Profile 2: maximum and minimum catch of a vertical-element, aluminum snowfence in Wasen-Heiterich, observations of 1960-1970 (field data and drawing by M. Peter, Brig).

Profile 3: maximum and minimum catch of a horizontal-element wooden snowfence in Pluetschessa, Ftan, observations of 1961-1967 (field data and drawing by H. Frutiger).

Profile 4: snow caught by a compact wall on "Pru dal Vent" above Alp Gruem; the wall produces a wave crest; as soon as the latter [wall] is covered over, snow erosion begins in the wave trough (field data by Ed. Campell).

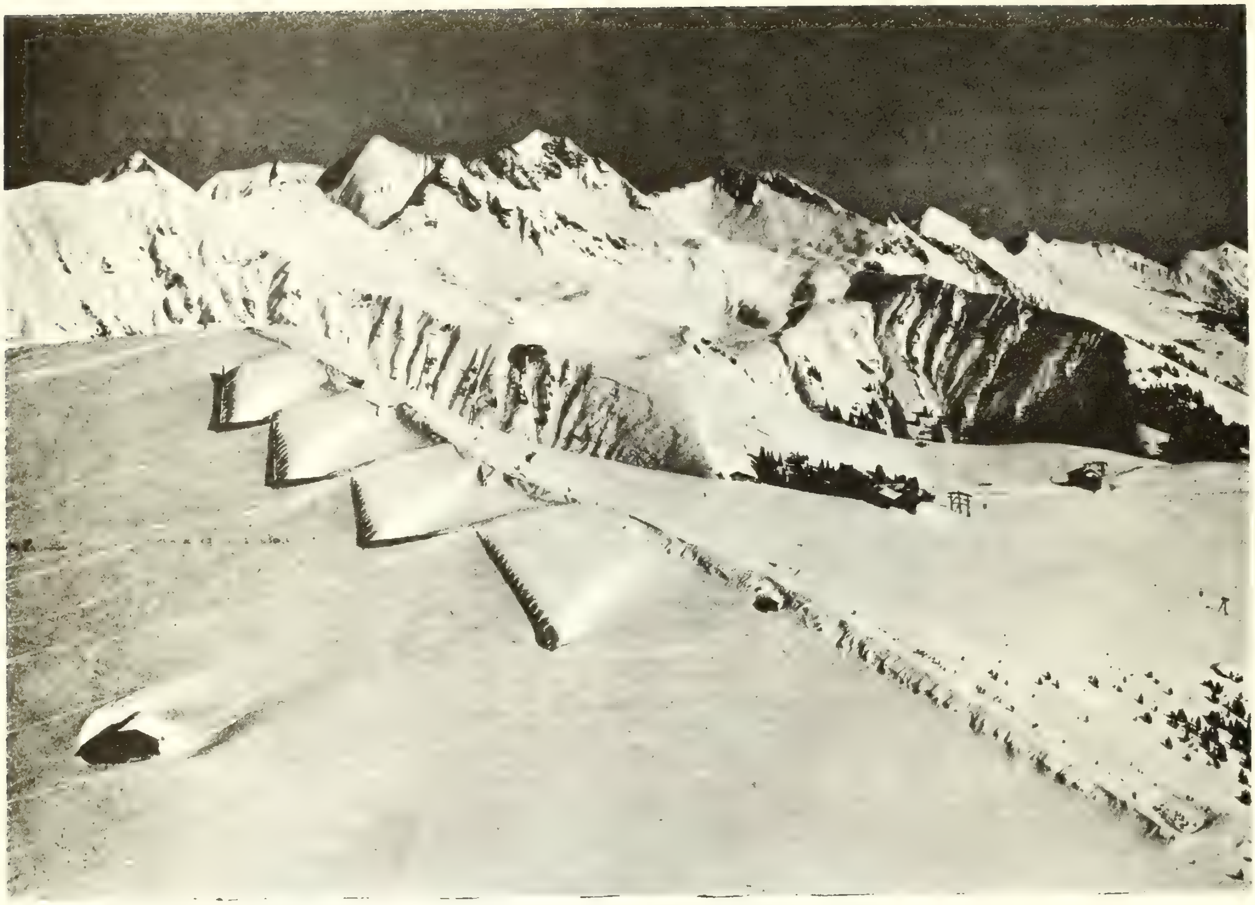
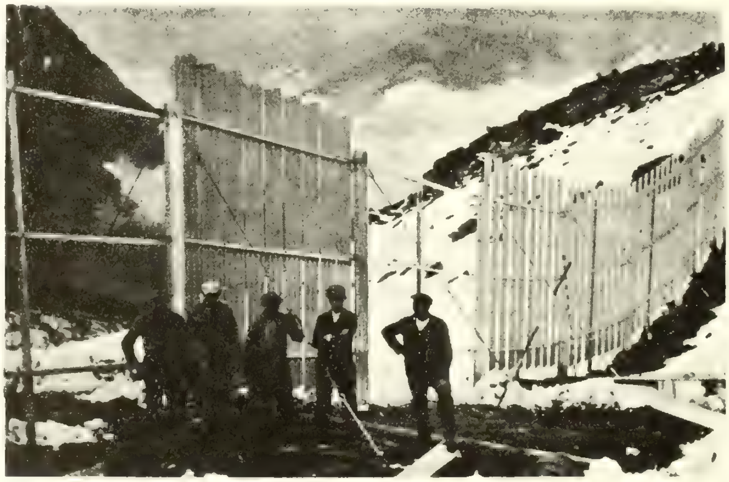


Figure 8. Snow catching structures (snowfences) above Adelboden with eight horizontal-element snowfences and snow bridges made of steel elements from the OeAM, 10 March 1970 (aerial photograph E. Wengi).

Figure 9. Assembly of a vertical-element snowfence of aluminum with two densities: left 90 percent, right 75 percent, Wasen-Heiterich project (Simplon). No difference in the effectiveness of the two designs could be observed (photo M. Peter).



4.2 Structures for the Promotion of Local Wind Transport

The most effective and most radical wind structures for hindering the formation of cornices and for limiting snow accumulation in the starting zone of the lee slope are jet roofs. An impressive example of a technically correct installation of this type has been built [12] by our colleague J. Manni (whose death was all too early) in the starting zone of the "Am Horn" avalanche project in Vals Precinct. The structure is built astride the ridge and has a hot galvanized steel framework. The roof of the structure has an inclination of 60 percent and produces a deflection of the wind flow into the lee slope where the snow is swept away. In various projects we find small wooden jet roofs introduced. Figure 11 shows a structure in the starting zone of "Ils Pals ob Ardez." This structure prevents the formation of cornices in a concave terrain depression where a Kolktafeln would not have been sufficiently effective.

The drift-snow ramp which has been installed at the recommendation of the Federal Institute for Snow and Avalanche Research behind the Weissfluhjoch station, produced a roof-shaped elongation of the windward slope which extended over the lee side. When drifting snow was blown over the drift-snow ramp, it was impossible for the snow to stick to the sharp ramp edge so that there was no formation of a cornice.

The snowdrift wall or Kolktafeln may be considered to be the simplest, most natural, and the most debated but cheapest form of wind baffle. The idea originates with the Austrian engineer Handl. In the course of time, numerous designs of these individual elements have been tested. The simple, light, trapezoidal board-wall having a height of 3-4 m and a width of 2-3 m is nailed to two posts which are buried about 1 m deep in the ground; it represents the only model which has been repeatedly employed in our country and in the neighboring Italian valleys (Figure 13). Gaps between the structure and the ground are avoided in this design in order for the wind scour to break through the snow cover down to the ground [2], (Figure 12). The trapezoidal form is actually an imitation of nature. Under free-standing groves and upright mountain firs whose bulky branches extend upward, we often find deep scours, while with deep-branched spruce trees, which display a more conical form, this phenomenon is missing. M. Zehnder [18] has established with careful measurements in St. Antoenien that trapezoidal walls cause a scour which is about one-third greater than that produced by rectangular walls of the same surface area set up in the same region. While

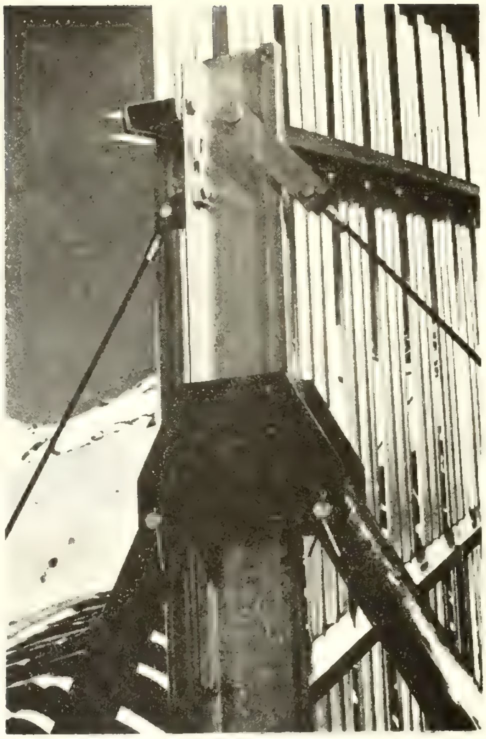


Figure 10. The light aluminum fences of the Schweifingen project above Zermatt had to be strengthened by tubular supports because they were not standing up to the wind load (photo 4. Bachmann)

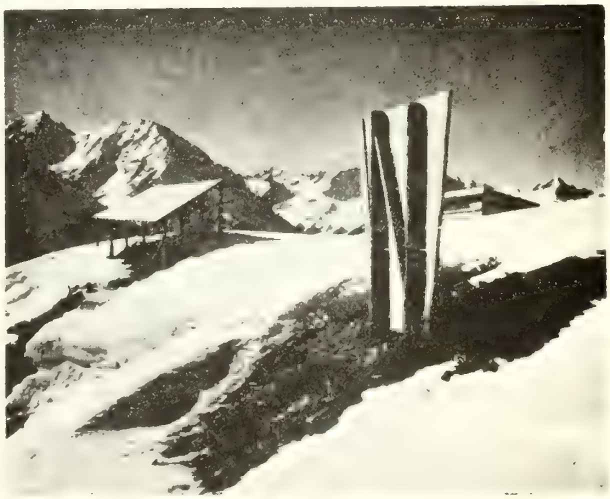


Figure 11. Wooden jet roofs (Left), combined with Kolktafeln in the starting zone of the "Ils Pals" project, Ardez, 19 February 1959 (photo Ed. Campell).

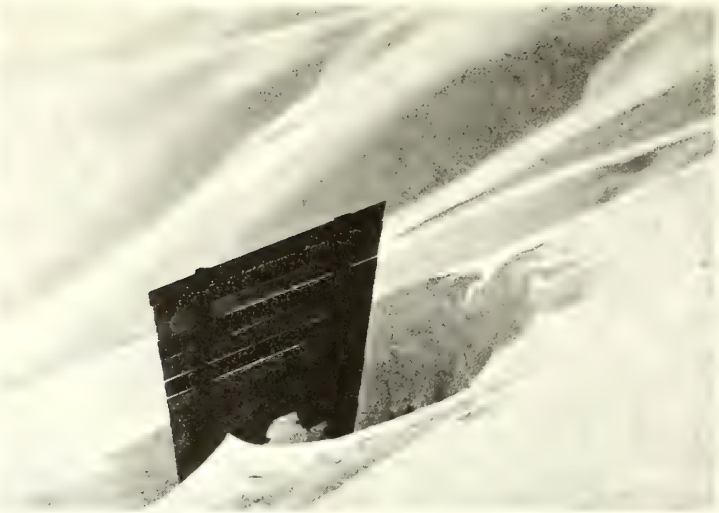


Figure 12. Effect of a trapezoidal Kolktafeln at the boundary of the "Albanas" avalanche control project near Zuoz, at a snow depth of 1.80 m, 26 February 1955. The upper edge of the structure is supposed to follow the inclination of the slope (photo E. Campell).

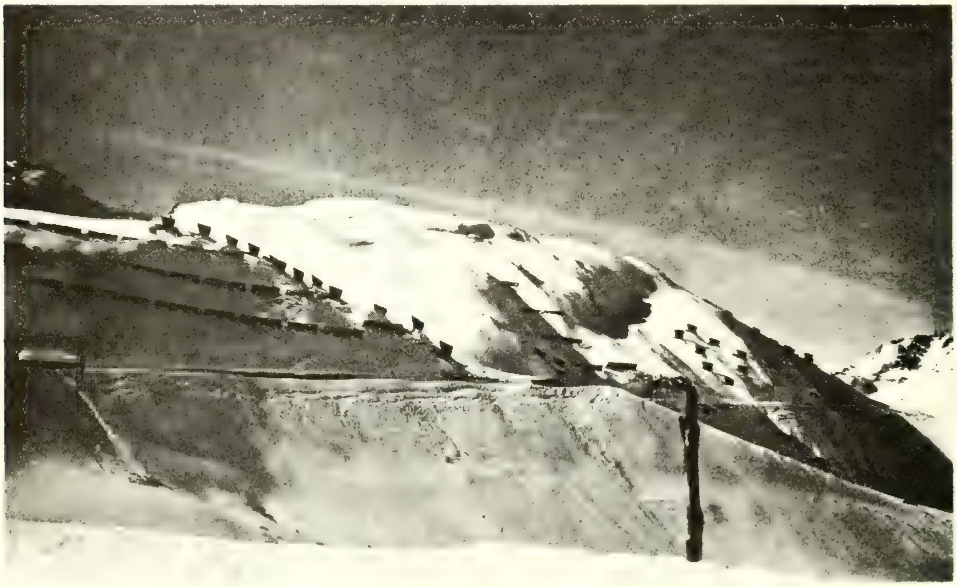


Figure 13. Protective structures along the Foscagno Pass road (between Livigno and Bormio) (2,290 m). On the left the Kolktofeln protect the supporting structures against drifts, on the right, small snow slabs are stablized by Kolktafeln, 25 March 1963 (photo Forest Inspectorate, Sondrio).

the former displayed an open scour-bottom, rectangular tables were already drifted-in on the lee side in January. Further, in May 1957, M. Zehnder demonstrated at the Kueenihorn that a single, normal Kolktafeln of 7.5 m^2 produced a scour-funnel of 103 m^3 [19].

On the slope, the Kolktafeln must be set up in the direction of the slope gradient to avoid damage by snow creep. On gliding snow slopes and in locations with frequent slushy snow, Kolktafeln should not be installed. On dry soils with relatively small water capacity, these phenomena are rarely encountered. A prerequisite is suitable terrain and possibility of making a fully effective reliable structure. This possibility of setting up the Kolktafel is established empirically. It is an advantage of these structures that they can be easily moved at little cost.

The Kolktafel is suitable for limited local effect. It serves as a stopgap, an emergency device, or to supplement other installations, for example, for relieving heavily drift-burdened supporting structures (Figure 13) or to prevent the formation of snowdrifts which have either not been controlled or only inadequately controlled by fences. The spacing of the individual structures is here decisive. In the "Las Vals" avalanche control project above Tschierv, after experiments over many years, using a distance between Kolktafeln of 7-8 m, we have succeeded in almost entirely preventing the formation of a cornice about 150 m long (Figure 14, situations 1 and 2). The conformation of the scour of the individual Kolktafeln was always the same.

For the purpose of separating avalanche controlled areas from uncontrolled areas, on both sides of the project in Albanas in Zuoz good results have been achieved using one row of Kolktafeln each (Figure 15). Since 1956, I myself have observed seven avalanches starting in the uncontrolled, bordering Val Buera and Val Urezza which broke out close to the row of Kolktafeln without penetrating into the controlled area. Subsequently, for safety, a long, horizontal-element snowfence 2 m high was erected partly inside the row of Kolktafeln, but this was covered over by snowdrifts. Snowdrift structures which are too low will later take revenge for any momentary parsimony.

In uninhabited zones, where the costs can be sustained since there exist no massive projects, snowdrift projects along the upper tree line will avoid many avalanches. There one must take note of the boundary lines between different vegetative communities, because they often reveal the location of avalanche paths. The vegetation serves in addition generally as the best indicator of the various snow sites [1]. Kolktafeln cannot replace other structures but they can effectively supplement them; they also perform good service in protecting afforestations and pioneer plantings for restocking [10].

A rationally designed snowdrift project has a permanent effect, in all kinds of weather, from the first snowfall to the opening up of the snow cover. A prerequisite is a certain amount of wind, which never stops for as much as a day in the upper subalpine zone and above.

Installations which are intended to remove snow from this starting zone have the disadvantage, that they guide the snow masses in the direction of the lower controlled slopes. This circumstance should be noted but excessive significance should not be attached to it. It is best for individual wind structures to be built of durable material in order that they can be effectively worked into the permanent control project.

It is the object of this discussion to confirm the fundamental rule that in avalanche control projects, depending upon the local conditions, the most rational types of structures must be combined with one another to give the most effective protection against avalanches. Any serious effort at avalanche structural control, but especially snowdrift structures, requires the builders to carry out several years of steady, thorough, winter patrols and winter observations; for the effect of this type of structure cannot be calculated in advance. A prerequisite is a knowledge of the principal wind direction in the construction region, which includes both down-slope and valley winds. Up-slope winds need to be considered only on moderately inclined slopes and on windward ridges. However, since the local wind direction is often influenced by the terrain, the introduction of an anemometer, combined with a wind vane [14], can permit a better prognosis. The construction superintendent must be a good observer who lives in the vicinity of the project, for these installations must in the beginning -- at least in part -- be provisionally erected and permanently constructed only after confirmation of their effectiveness. Nor should one neglect, after installing the facility, continuous checking, maintenance, and necessary supplementation of the installation. For here, too, the proverb of Wilhelm Busch is true:

> "Oh, how much is still concealed
> that is still beyond our ken!"

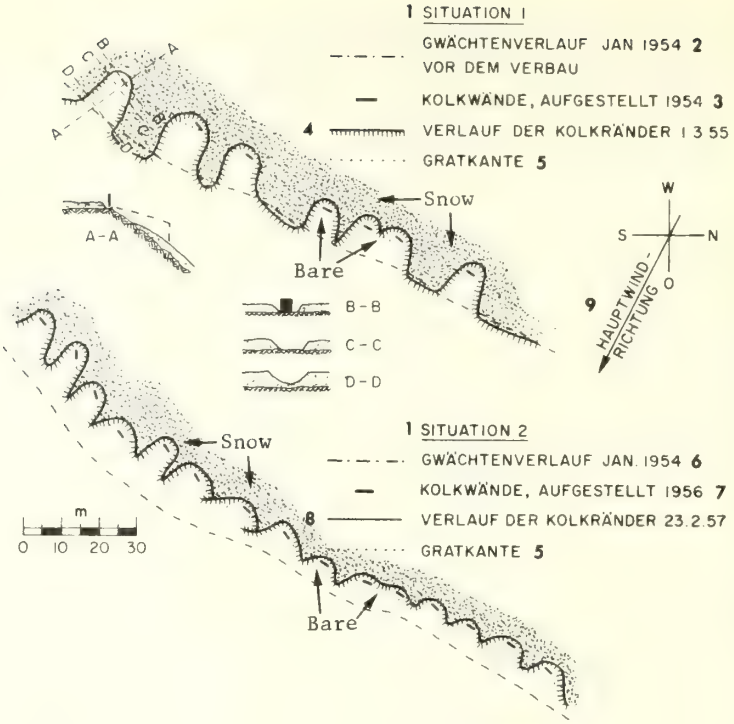

1 SITUATION 1
GWÄCHTENVERLAUF JAN 1954 VOR DEM VERBAU 2
KOLKWÄNDE, AUFGESTELLT 1954 3
4 VERLAUF DER KOLKRÄNDER 1.3.55
GRATKANTE 5
A
B
C
D
A-A
B-B
C-C
D-D
Snow
Bare
W
S
N
O
9 HAUPTWIND-RICHTUNG
1 SITUATION 2
GWÄCHTENVERLAUF JAN. 1954 6
KOLKWÄNDE, AUFGESTELLT 1956 7
8 VERLAUF DER KOLKRÄNDER 23.2.57
GRATKANTE 5
m
0 10 20 30

Figure 14. Wind structures "Alp da Munt," near Tschierv, 2,220 m above sea level (field data and evaluation, Ed. Campell).

Key:

1. Plan view
2. Edge of the cornices, January 1954, before the structures were built
3. Kolktafeln, set up 1954
4. Edge of snow, 1 March 1955
5. Ridge crest
6. Edge of cornices, January 1954
7. Kolktafeln, set up 1956
8. Edge of snow, 23 February 1957
9. Main wind direction

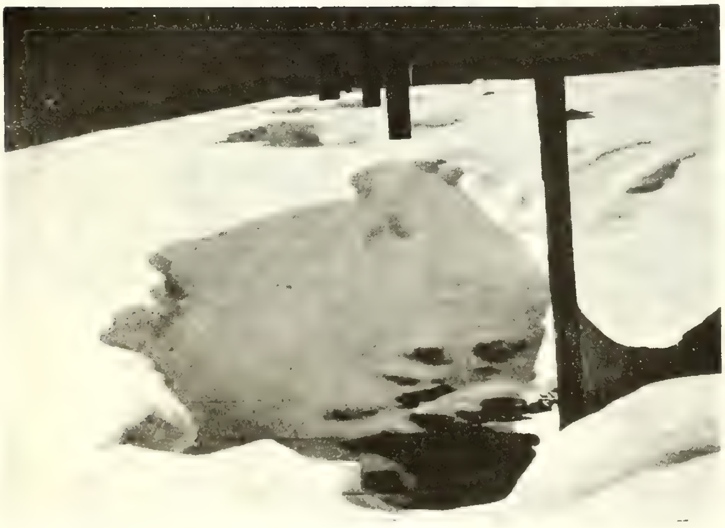


Figure 15. Row of Kolktafeln separating the "Albanas" supporting structures from the uncontrolled avalanche starting zone of Val Buera. The scour hollow reaching the ground interrupt the snow layers and also the hardened scour-walls contribute to snow stabilization, 26 February 1955 (photo E. Campell).

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English Translation of German Titles

[1] Principles and Application of the Provisional Wind-Snow Ecogram.
[2] Contribution to the Theoretical Foundations of Avalanche Defense Construction.
[3] Snow-Drift Walls and Their Application in Avalanche Control Structures.
[4] Experimental Measurements With Snow Fences in the Winters 1940/41 and 1941/42.
[5] Snow Studies in the Upper Valais and Their Application to Avalanche Control Structures.
[6] Snow-Drift Control Structures in Pluetschessa, Ftan.
[7] Recent Developmental Tendencies and Problems of Avalanche Control Structures in the Starting Zone.
[8] On the Significance, Nature, and Distribution of Wind-Dependent Structures in Avalanche Defense Construction and Avalanche Prevention.
[9] The Vegetation on the Stillberg.
[10] Wind-Walls for the Protection of Afforestations.
[11] Avalanche Control Structures and Afforestation in Cluenas-Pluetschessa of the Community of Ftan.
[12] Note on Snow-Drift Control Structures.
[13] Wind as a Site Factor in Afforestations of the Sub-alpine Zone (Stillberg Alp in Dischmatal, Graubuenden Canton).
[14] Snow-Drift Control Structures.
[15] Problem Formulation for the Snow-Drift Testing Field in Sils-Maria, Engadine.
[16] Jet Roofs, Snow-Drift Ramps, and Snow-Drift Walls.
[17] The Limits of Modern Avalanche Control Structures in the Starting Zone.
[18] The Effect of a Kolktafel.
[19] Observations of Snow-Drift Control Structures in St. Antoenien in the Winter 1956/57.
[20] Snow and Avalanches in the Swiss Alps.

X. DEFLECTING STRUCTURES (Eugen Sommerhalder, Weissfluhjoch/Davos)

1. Introduction

Structural protective measures against avalanches are determined by the nature of the objects to be protected (settlements, alpine roads and railways, as well as individual objects).

Supporting structures in the starting zone serve principally for dealing with avalanche problems in settled areas and only occasionally along communications arteries. In most cases, these protective measures are financially unacceptable for transportation routes or they are technically impossible and unnecessary for individual structures. Hence, in such cases, the avalanche problems are resolved by measures taken in the track and runout zone, by guiding the moving snow masses, deflecting them, slowing them, or stopping them. The technical and financial resources at our disposal permit us to consider various possible protective procedures such as galleries, guide dikes, deflecting dikes, avalanche wedges, retarding structures, and arresting dikes. In the following discussion, we shall examine these types of construction -- particularly galleries -- in some detail.

2. Questions of Safety

2.1 Safeguarding a Highway Against Avalanches

In a potential forest zone at lower elevations, when avalanche protective measures are required, supporting structures with simultaneous afforestation are preferred whenever possible.

If the upper boundary of the avalanche path lies above timberline so that avalanches in gorges, gullies, or straight clearings break through the forest, then, depending upon the size of the region invaded, financial and engineering factors will determine the type of structures required.

Let us suppose, for example, that a stretch of highway 100 m long is to be protected against avalanches. The relatively small avalanche path has a construction area of 5 hectares. The cost of supporting structures runs to about 0.5 million francs per hectare, those of a gallery to about 10,000 francs per running meter. The financial outlay for the supporting structures amounts to 2.5 million, that for the gallery to 1 million francs.

At high elevations where the dense forest disappears and in its place there are only individual groups of trees and then with increasing elevation open slopes and rocky terrain, the gallery clearly offers the highest level of safety. Its protective effect relates not only to avalanches but also to other external agencies acting on the highway, such as the results of summer storms (rock falls, landslides). In addition, the cost of snow removal to keep the highway open in winter is entirely eliminated or held within tolerable limits. Galleries are also built on stretches where snow drifting is so severe it is impossible to handle it even by continuous operation of conventional snow removal equipment.

The choice of the alternatives "supporting structures or gallery" is not decided just by the question of cost, but also with regard to the degree of winter safety to be sought for the highway concerned. With the gallery, one obtains an absolute safety and with supporting structures a limited safety associated with some residual risk which under some circumstances, or important main arteries, is not acceptable. Also, if the road is exposed only to small avalanches which can start just below or within the structures then these apparently insignificant events suffice to bury persons and vehicles or knock them off the roadway.

2.2 Winter Safety on Highways

In regions where, during the winter, alpine routes serve only local traffic and for the most part are used by natives or people familiar with the area who know the danger sites and also can evaluate the avalanche risk in conjunction with weather conditions, avalanche accidents can be largely avoided. The mountain dweller, familiar with the conditions, in earlier days also accepted the inconvenience of having individual settlements occasionally cut off from one another and the necessity of reestablishing communications with laborious snow removal operations. In many localities, galleries were built only in the paths of especially large avalanches primarily in order to deal with the massive avalanche deposits and to facilitate the clean-up. This engagingly "primitive" but risk-taking attitude is unthinkable today. Many mountain dwellers, particularly the younger generation, are employed outside the valley. Small schools in remote settlements are being closed down and combined at central locations in the valley. The subsequent education, whether it be learning a trade or a profession, takes place outside the valley. Hence, the residents in the locality are increasingly dependent upon having a thoroughly winter-safe system of communication; it can become an issue of existence itself.

On the other hand, the progressive and large-scale elaboration of pass highways and main highways as well as the promotion of tourism in the alpine region leads to a situation in which the means of communication are used to an increasing degree by travelers unfamiliar with the mountains and having no idea of winter conditions. Therefore, increased attention must be given to avalanche conditions and a degree of winter safety must be sought which is either complete or as great as possible.

By complete winter safety we mean the continuous accessibility of a highway without avalanche risk. In certain cases, severe snow drifting is also included, which can endanger and interfere with traffic.

The concept of limited winter safety is relatively new. It asserts that the road concerned is to be considered as not winter safe but it requires temporary closure only in extraordinary avalanche situations. The stretches frequently crossed by avalanches are protected by structural measures (galleries). Translated into practice, a road possessing limited winter safety is one which has 1 to 3 days of traffic interruption annually as a result of road closures as preventative measures against anticipated avalanches.

2.3 Clarification of the Avalanche Conditions

2.3.1 Avalanche Cadastral Survey

The observation and recording of all avalanche descents into settled valleys and their listing in so-called avalanche cadastral plans provide rather reliable documentation for evaluating avalanche conditions affecting a highway. They permit conclusions with regard to the localities in which one must reckon with avalanches, with regard to the types of avalanches (flowing avalanches, powder avalanches, or mixed types) and they tell us with what frequency and in what magnitude they can occur.

In unsettled regions or in newly located alpine transportation routes, the observations are lacking or are only scanty and deficient. With regard to the avalanche cadastral survey, it must be clearly understood that this is merely an inventory of previously observed avalanches which, as a rule, extends only over a relatively short period of time amounting to one to two generations, in which rare avalanche events normally cannot be included.

2.3.2 Avalanche Danger Map

The avalanche danger map is created on the basis of a detailed terrain evaluation, an avalanche cadastral survey (to the extent that it is available) and with the aid of avalanche engineering calculations which take into account local climatic conditions. The danger map represents the endangered zones and road stretches in plan form and describes the avalanche frequencies to be expected in the individual zones (avalanche paths) as well as describing the degree of winter safety on the routes (highway) as follows:

Danger Zones

Starting Zone, Paths & Tracks	Frequency of Occurrence of Avalanches
Red	Mean recurrence interval of 30 years or less.
Blue	Mean recurrence interval between 30 and 60 years.

Dangerous Routes

Highway	Winter Safety
Red	Not winter-safe. Routes with acute avalanche danger. (Depending upon the safety requirement which has been set, the blue danger zone may also be included.)
Blue	Limited winter safety. Route is only rarely endangered by avalanches, in extraordinary to extreme situations.
Yellow	Limited winter safety. Only dust avalanche activity.
Orange	Not winter-safe. Routes with very severe snow drifting.
Green	Winter safe. Routes where avalanche danger is absent or improbable.

3. Galleries

3.1 Task and Mode of Action of the Gallery

As avalanche protection for a highway, which runs through the terrain like a narrow band, normally only a roofing-over in the form of galleries can be considered at acceptable financial outlay. The avalanches are either conducted over the gallery or they are partially deposited on the roof in their run-out region without disturbing the traffic on the highway. Figure 1 is an example of a gallery which leads through interconnected avalanche paths lying on steep slopes.

3.2 Avalanche Forces and Stresses on the Gallery

In planning avalanche galleries, it is necessary to know the nature and magnitude of the forces to which the protective installations are exposed in the most unfavorable case. The gallery does not constitute an actual obstacle which noticeably affects avalanche motion. The force effect consists essentially of the deflection force and the friction which the stationary and the moving snow loads apply to the gallery roof. The gallery design must be dimensioned in terms of these forces.

3.2.1 Experimental Derivation of the Forces Acting on a Gallery

In order to get a clear idea of the magnitude of the forces, in the year 1962, mechanical measuring devices were specially designed for this purpose and installed on gallery roofs (Lukmanier, Schoellenen, and Vintzay VS) [1]. Every winter the maximum values of normal and shear force produced by avalanches and avalanche deposits are measured. In order to be able to draw generally valid conclusions from this, the measurements must extend over a series of years.

These force measurements refer throughout to flowing avalanches. The powder avalanches sweep over the gallery and generate only insignificant frictional forces. Suction forces can occur on small galleries completely inundated by powder avalanches. According to observations and computations up to now, values of $-p < 100$ kg/m^2 occur. The previously

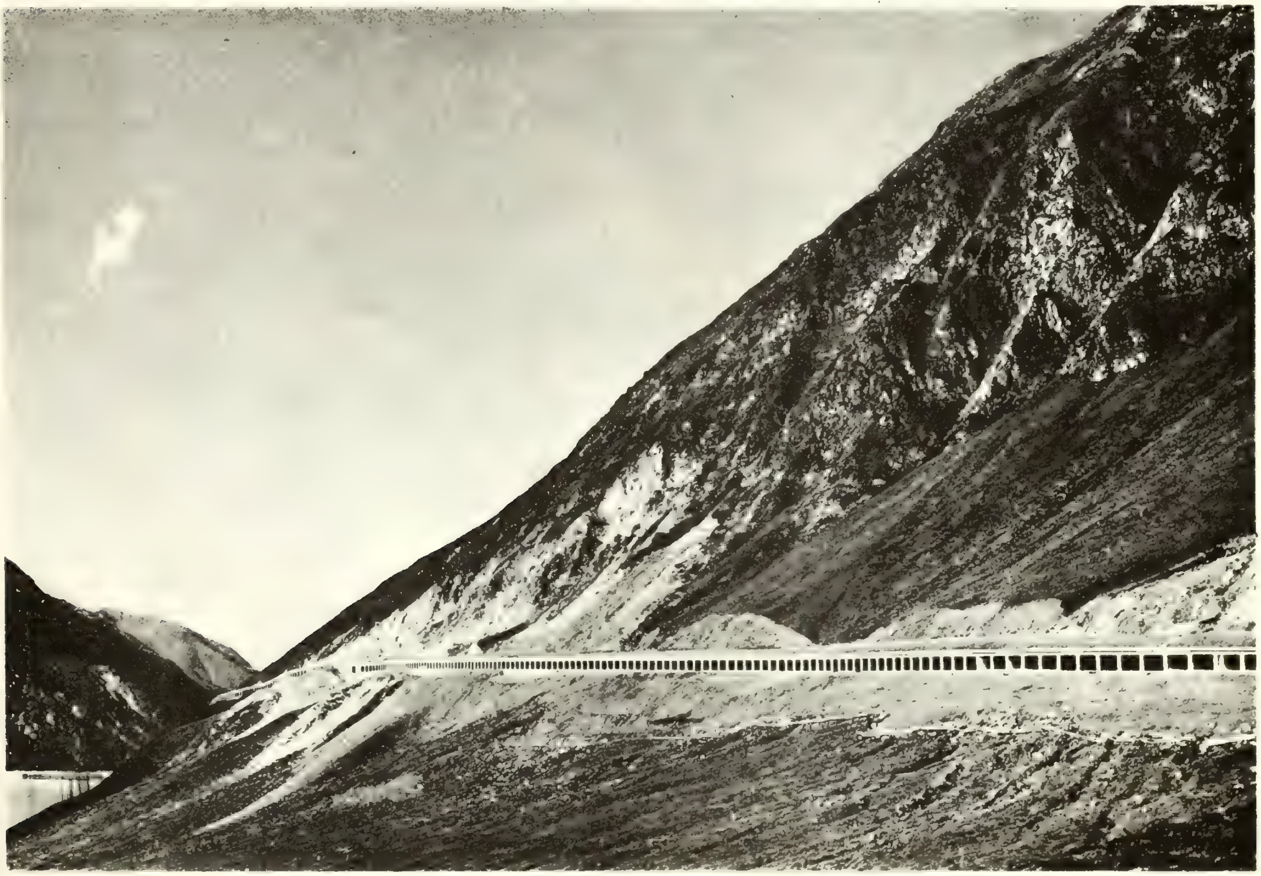
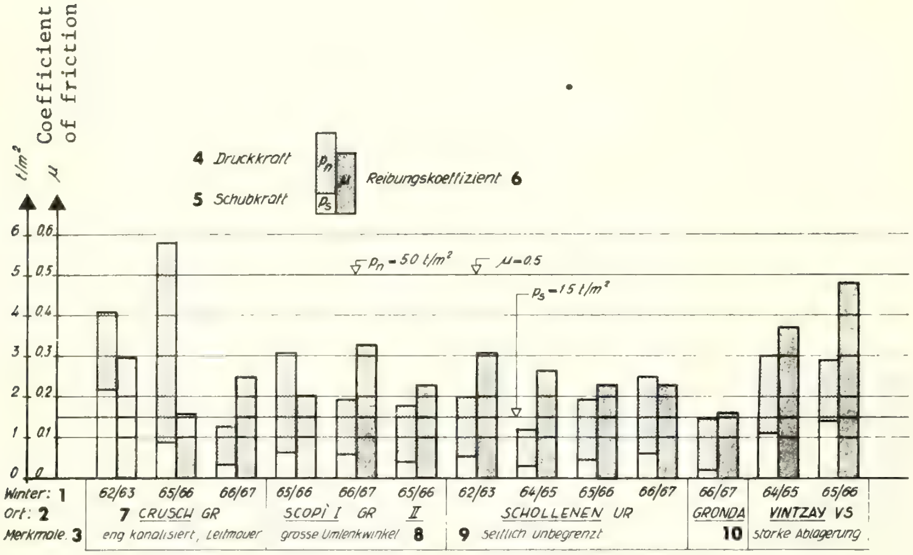


Figure 1. Gallery on the Lukmanier highway, along the Sa. Maria impounded lake (photo E. Wengi).

mentioned measuring devices serve particularly for the investigation of frictional forces. In order to be able to compute these quantities for each special case it is necessary to derive a coefficient μ which arises as the measured quotient of shear and normal force. As a supplement to the field measuring devices, analogous but more precise experiments are being carried out [2] with electrical measuring methods on the snow slide path near the Federal Institute for Snow and Avalanche Research on Weissfluhjoch. The provisional measurement results [3] are contained in Figures 2 and 3. In Figure 2, the measured compression and shear forces as well as the coefficients of friction derived therefrom may be seen. In Figure 3 is shown the profile of the average of the coefficient μ evaluated from 14 measurements over the breadth of the gallery. The highest average value is μ = 0.32, the average over



Key:
1. Winter
2. Place
3. Characteristics
4. Compression force
5. Shear force
6. Coefficient of friction
7. Narrowly canalized, guiding wall
8. Large deflection angle
9. Laterally unbounded
10. Heavy deposit

Figure 2. Measurements on gallery roofs: normal force, shear force, and calculated coefficients of friction.

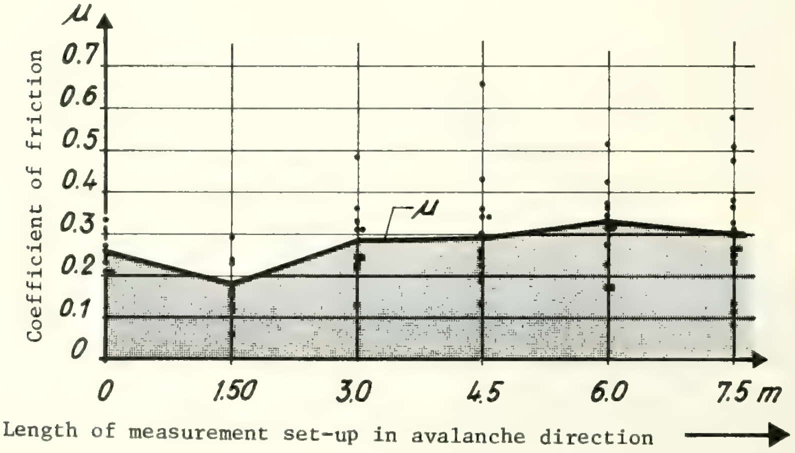


Figure 3. Coefficient of friction, average of 14 measurements.

the breadth of the gallery (7.50 m) is $\mu = 0.27$. For calculations, a coefficient of friction $\mu \geq 0.40$ is assumed. In Figure 4, there is shown an individual gallery with a measuring device installed.

3.2.2 Computational Derivation of the Forces Acting on a Gallery [1], [4], [5]

An assumed extraordinary avalanche situation serves as the initial condition for all avalanche engineering discussions.

The stresses produced by snow are composed in general of the following components:

a. Weight of the snow deposit present on a gallery before or during the descent of an avalanche, in special cases it includes creep compression also.

Conventional assumptions for average conditions:

Density of the snow cover $\gamma_\alpha = 400$ kg/m^3
Magnitude of the snow cover on the roof during descent of the avalanche
$d_a = 1.50\text{-}2.00$ m

Calculation: normal force

$$\underline{p_{na} = \gamma_a \, d_a \cos\beta} \quad (\mathrm{kg/m^2})$$

where β denotes the angle of the roof inclination

b. Weight of the avalanche flowing over the gallery.

Conventional assumption:

Density of the flow avalanche

$$\gamma_t = 300 \ \mathrm{kg/m^3}$$

Calculation:

Flow height d_t

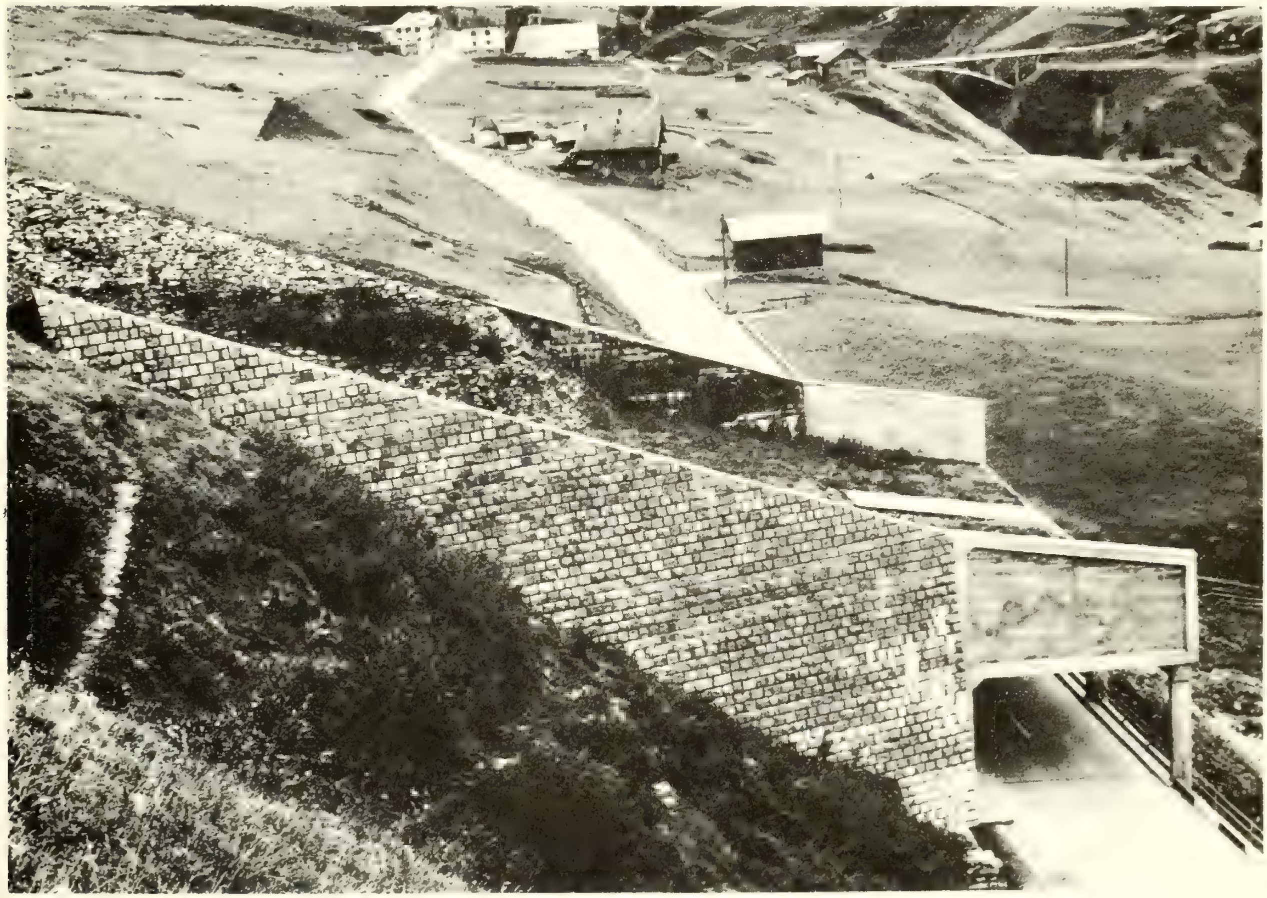


Figure 4. Avalanche gallery with built-in measuring device: in the foreground are guide walls and dikes, in the middle and in the background of the picture deflecting dikes are visible (photo E. Wengi).

Normal force $\underline{p_{nt} = \gamma_t\, d_t \cos\beta}$ (kg/m²)

c. Deflection force resulting from a change in the flow direction of the avalanche constrained by the gallery roof, through a deflection angle α.

Calculation:

Flow velocity of the avalanche v_t
Normal force $\underline{p_{nd} = \frac{d_t}{L} \frac{\gamma_t}{g} v^2 \sin\alpha \text{ (kg/m}^2\text{)}}$

(for the remaining symbols see Figure 5, loading cases)

The gallery and its covering should preferably be so arranged that the gradient break (deflection angle) occurs at as great a distance as possible uphill of the gallery.

d. Total of the normal forces which act upon the gallery in an avalanche descent. $\underline{p_n = p_{na} + p_{nt} + p_{nd}}$ (kg/m²)

e. Friction forces.

Conventional assumption:

Coefficient of friction $\mu = 0{,}4$

Calculation: components consisting of

Stationary load $\underline{p_{sa} = \gamma_a\, d_a \sin\beta}$ (kg/m²)
Moving avalanche load $\underline{p_{st} = \mu\, p_{nt}}$ (kg/m²)
Deflecting force $\underline{p_{sd} = \mu\, p_{nd}}$ (kg/m²)

f. Total of the friction forces which act upon the gallery in an avalanche descent. $\underline{p_s = p_{sa} + p_{st} + p_{sd}}$ (kg/m²)

g. Weight of the avalanche deposit.

Conventional assumption:

Density of the deposit

Calculation: $\gamma_a' = 500$ kg/m³

Mean deposit depth d_a'
Normal force $\underline{p_{na}' = \gamma_a'\, d_a}$ (kg/m²)

h. Additional earth pressure on the uphill gallery wall caused by the friction forces or deposit forces acting, above the gallery, on the ground.

i. Static snow pressure on the downhill side of the gallery front when the gallery is completely surrounded and covered by the avalanche deposit.

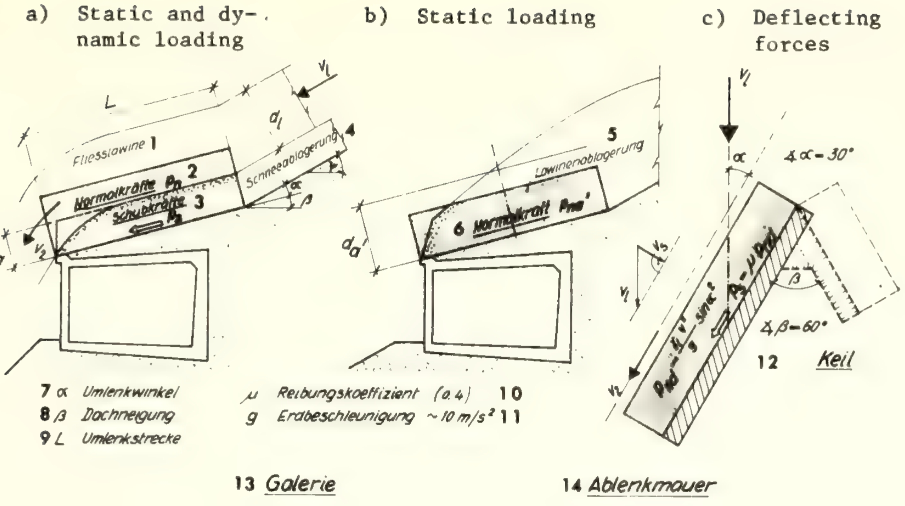
k. Forces caused by avalanches which do not flow from the mountain side over the gallery roof but flow toward the structure from the valley side opposite the gallery.

But naturally the forces which have been mentioned will never all occur simultaneously, at least not in their maximum magnitude. The calculation of the avalanche velocities, of the depths of flow and deposit as well as of runout distances are not treated in this article in any more detail; these should be determined by trained avalanche specialists.

For designing a gallery, the possible loading cases shown in Figure 5 need to be considered: a) static and dynamic load (avalanche descent), b) only static load (avalanche deposit). In each case, the most unfavorable loading of each type is to be considered. Figures 6 and 7 serve as an illustrative example in which the loadings acting upon an avalanche gallery are schematically represented in cross-section. Figure 6 shows the forces on the gallery roof and on the back wall of the gallery, resulting from the stationary load. Figure 7 refers to the case of stress during descent of an avalanche in which static and dynamic loads occur.

4. Guidance Dikes

Wherever gully-shaped avalanche tracks discharge onto fan-shaped cones of deposit in the flatter valley floor and there is a possibility of marked lateral extensions of the avalanche and changes in its direction, the avalanche path can be limited in its breadth by means of guidance dikes, i.e., can be canalized. In this way, it is possible to reduce the length of the relatively expensive gallery to a certain size. These dikes or walls should as a rule be carried up to the roof of the gallery (Figure 4) to positively prevent a lateral outbreak of the avalanche over the entrances to the gallery and onto the road. It is a mistake to constrict an avalanche track funnel-wise with guidance dikes toward the gallery in order to achieve higher savings in gallery lengths. The constriction makes the outflow of the avalanche difficult. Pile-ups occur on the roof which lead to an excessive loading of the structure. The snow masses flowing behind the avalanche front fall to left and right of the gallery ends onto the highway. Guidance dikes are also used to protect settlements and individual objects. The determination of the position, the height, and the length of a guidance dike is carried out on the basis of a careful study of the character of the ground and on the basis of avalanche computations.



a) Static and dynamic loading

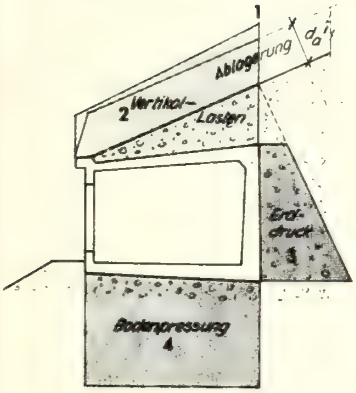
b) Static loading

c) Deflecting forces

Figure 5a, b, c. Various loading cases.

Key to Figure 5a, b. c:

1. Flow avalanche
2. Normal forces
3. Shear forces
4. Snow deposit
5. Avalanche deposit
6. Normal force
7. Deflection angle
8. Roof inclination
9. Deflection interval
10. Coefficient of friction
11. Gravitational acceleration
12. Wedge
13. Gallery
14. Deflecting wall



Key to Figures 6 and 7:

1. Deposit
2. Vertical loads
3. Earth pressure
4. Compression of the ground
5. Horizontal load
6. Flow avalanche

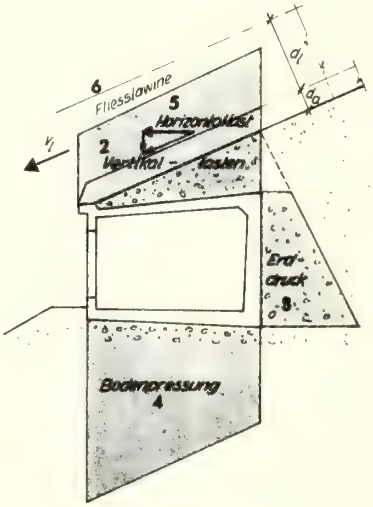


Figure 6. Stress on the gallery resulting from static loads. Schematic loading plan.

Figure 7. Stress on the gallery. Schematic loading plan for static and dynamic loading cases.

4.1 Computational Derivation of the Height of Guidance Dikes

In avalanche tracks where as a consequence of the gradient no very large avalanche deposits can form, one must take into account the naturally deposited snow cover and one must determine the flow height of the avalanche.

Assumption:

Magnitude of the snow cover $d_a \geq 1.50$ m

Computation:

Magnitude of the flowing avalanche d_f
Dike height above the floor of the avalanche track $D = d_a + d_f$

It is more difficult to determine the dike height in the avalanche runout region with terrain inclinations below 17°. Depending upon the locality, in the course of a winter several avalanches both small and somewhat larger may run which leave behind corresponding deposits whose magnitude is difficult to evaluate. For subsequent large descents, adequate space will no longer be available -- otherwise the guidance installations would have to be overdimensioned. Flat runout stretches after sharp gradient breaks are especially critical. Here, under some circumstances, the wisdom of employing guidance dikes may be questioned because the required dike heights can hardly be attained with reasonable means. In such situations, the original avalanche track width may be constricted only very slightly or not at all.

Assumption:

Magnitude of the deposit in front of the extraordinary avalanche descent (estimate or computation) d_a

Computation:

Magnitude of the flowing avalanche d_f
Velocity of the avalanche v_f
Mean deposit depth $d_a' = \frac{v_f^2}{4g} + d_f$

Dike height above the descent path floor

$$D = d_a + d_a'$$

For guidance walls in the runout zone, one must also take into account the static snow pressure on the inner side of the wall and, in certain cases, one must also allow for a deflecting force.

5. Deflecting Dikes

In contrast to the guidance installations, deflecting dikes are intended to deflect a flowing avalanche into a desired direction or restrain a lateral outbreak after the track changes direction. Deflecting installations have practically no effect upon powder avalanches.

The protective installations are designed in accordance with their mode of action. Their effectiveness does not depend solely upon the height of the installation but also upon the slope of the terrain and the deflection angle. In the all-too-flat avalanche runout region, instead of a deflection they cause a pile-up and a back-filling of the installation. In steep tracks of large avalanche paths, very large dike heights are required (depending upon the choice of deflection angle) which can entail difficult and hardly soluble construction problems. Deflecting dikes or deflecting walls promise success in locations where they contribute to an elevation of the lateral gully boundaries and to a magnification of the channel cross-section, thus hindering the outbreak of avalanches (for example, after the track changes direction with subsequent outflow channels running transverse to the fall-line (Figure 8a)). Successful deflection of the avalanche depends largely upon the size of the deflection angle. If the angle of encounter with the obstacle is too great, the descending flow avalanches leap over the dike and only those snow masses moving sluggishly in the rear are deflected. The deflection angle should not exceed about 30°. The smaller the angle the better the avalanche deflection and the smaller are the forces (deflecting force and friction) acting on the deflection installation.

5.1 Computational Derivation of the Height of Deflection Dikes

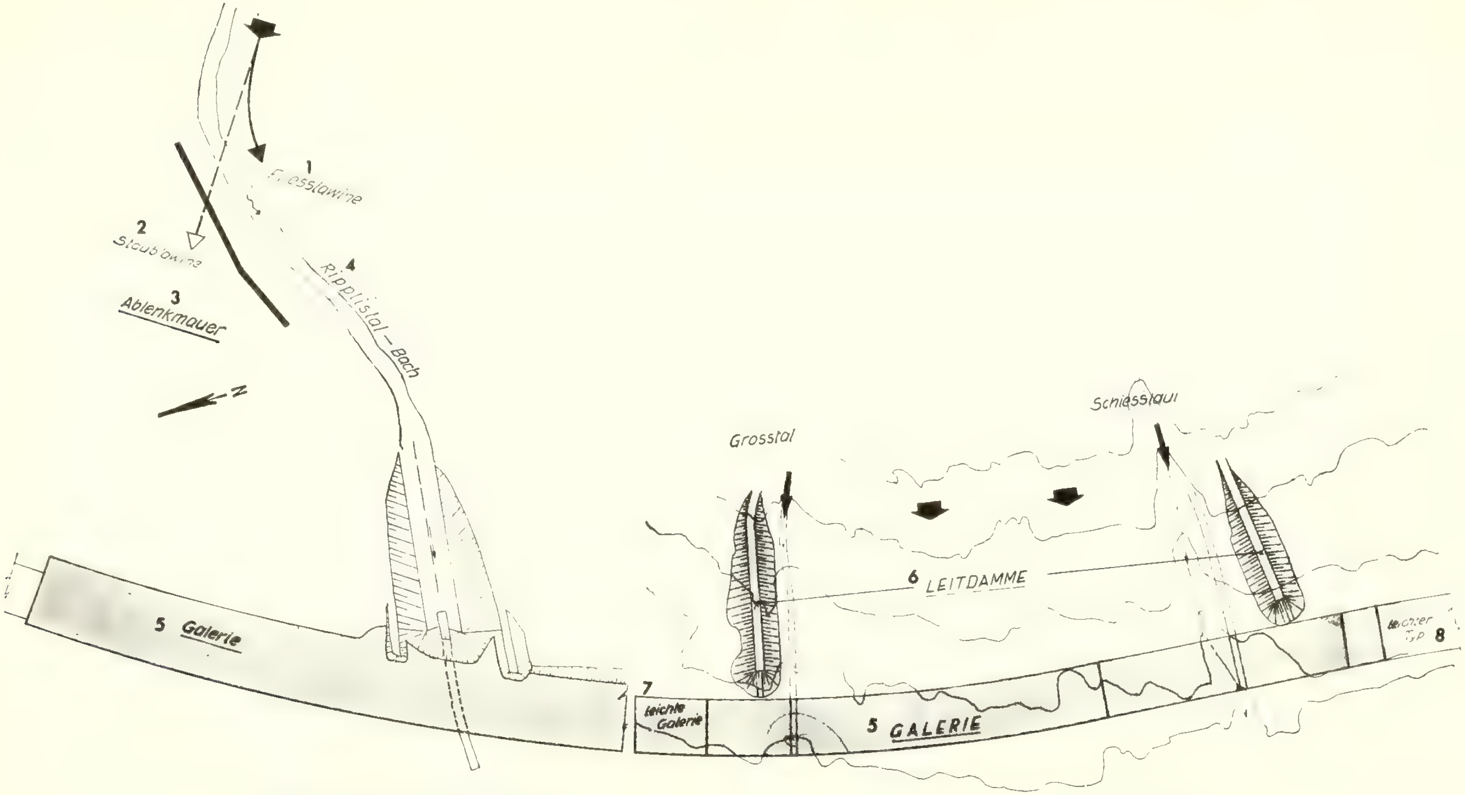
The sketch (Figure 9) shows an example of a deflecting dike on a low spot in the ridge out of which large avalanches emerge and endanger the edge of a village.

From the scientific aspect, the following must be calculated [5]:

The existing discharge quantity (avalanche snow) Q_{vorh}
Magnitude of the flowing avalanche in the track above the protective installation d_f
Velocity of the avalanche v_f

The required height of the protective installation is determined as follows: The following quantities are first established in the given gully cross-section.

Height of the channel boundary measured from the floor D_{geg}



a) Deflecting installation

b) Guidance installations

Figure 8a, b. *Gallery, guidance, and deflection dikes; example from experience with the National Highway N2, in the Canton of Uri.*

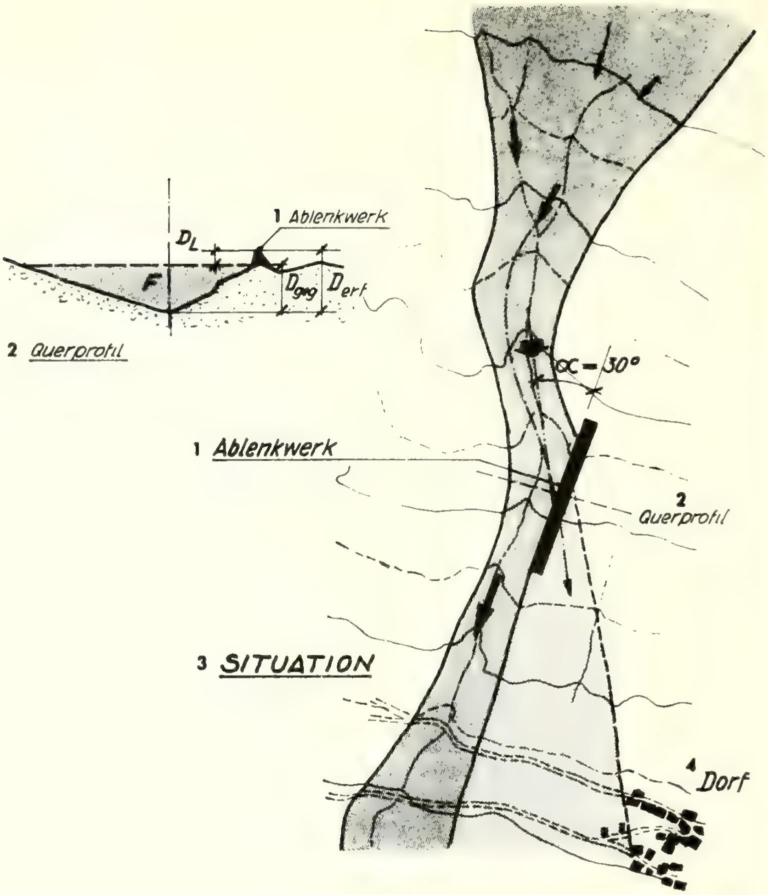
Key:

1. Flowing avalanche
2. Powder avalanche
3. Deflecting wall
4. Ripplistal stream
5. Gallery
6. Guidance dikes
7. Light gallery
8. Light type [gallery]

Figure 9. Example of a deflection installation, situation plan.

Key:

1. Deflection installation
2. Transverse profile
3. Plan view
4. Village



Cross-sectional area of the channel F_{geg}
Allowable discharge quantity in the given cross-section Q_{zul}

The allowable and the existing discharge quantities are compared with one another. The following condition must be satisfied (without taking into account the deflection):

$$Q_{zul} > Q_{vorh}$$

What is now sought is the required height D of the deflection installation.

Using the component of the velocity vector $v_{:}$ perpendicular to the deflection wall v_s, the pile-up height d_{max} is calculated. In this way one gets the superelevation d_{Δ} compared to the flow height $d_{:}$ at the outer side of the descent path curvature.

$$\text{Superelevation} \quad d_{\Delta} = \frac{{v_s}^2}{2g}$$

The required elevation of the wall crown and dike crown above the descent path floor is obtained by

$$D_{erf} = d_a + d_{:} + d_{\Delta}$$

The effective height of the protective installation D_L is derived from

$$D_L = D_{erf} - D_{geg}$$

Design of the deflection installations to meet the avalanche forces is done on the basis of the loading plan in Figure 5.

6. Avalanche Wedges

The use of the avalanche wedge with its relatively restricted protective capability is to be considered whenever individual objects, such as isolated buildings, high-voltage towers, and cable-car towers stand in an avalanche path. As a rule, the wedge is placed directly at the object or in its immediate neighborhood. In contrast to deflection dikes, the avalanches are separated and the snow masses guided to left and right past the object to be protected. The side of the wedge must have sufficient length in order that the parts of the avalanche flowing behind the wedge will not strike the object.

6.1 Computational Derivation of the Height of Wedges

The flow heights and velocities of the flowing avalanches must be calculated on a theoretical basis.

The height of the wedge walls and the stress produced by avalanche forces must be determined as in the case of deflection dikes under Section 5.1. The angular aperture of the wedge should not exceed 60°.

7. Concluding Remarks

It is the purpose of this study, with regard to the continuing expansion of the alpine highway system, to display the associated avalanche problems and possible protective measures. We do not enter into the subject of theoretical avalanche calculations because this would carry us too far within the limits available. For the practitioner, we have just given a few recipe-type indications.

Deflection construction for the protection of highways increased very much in significance in the last 10 years. Today it has about the same importance as supporting structures in the starting zone, for the protection of settlements and other objects.

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English Translation of German Titles

[1] Stresses Applied to Avalanche Galleries by Snow.
[3] Compression and Shear Measuring Devices on Avalanche Galleries, Description of the Installations, and Results Thus Far.
[4] Principles of Structural Control of Avalanches.
[5] Avalanche Forces and Object Protection.

XI. RETARDING STRUCTURES (Hans Doenni, Brig)

Structures built in avalanche paths with the object of reducing avalanche velocities and of shortening the avalanche path are called retarding structures. It is intended that the avalanche should be split up by obstacles into as many arms as possible, thus losing energy and finally being brought to a halt. It is not arrested suddenly but slowed gradually and the energy dissipation should not take place directly at the obstacles but primarily within the avalanche itself. This method of construction developed from experience with splitting wedges and deflecting dikes. Except that the obstacles are not placed in front of the objects to be protected but in the path of descent of the avalanche. The splitting of the avalanche at the most forward splitting wedges is followed in a field of further obstacles by an additional collision of the split-up avalanche arms with one another and further encounters of these with the next wedges. By the introduction of obstacles into the avalanche path the normal flow process of the snow masses is disturbed, the internal friction of the avalanche as well as friction between snow and the slide path are amplified and thereby energy is dissipated and the flow motion or impact force is reduced.

The ideas underlying retarding structures seem evidently correct and this method of control is promising.

What experience has thus far been acquired in retarding structures and under what assumptions can such experience be applied with a corresponding effect? Austria, the pioneer country in the use of retarding structures, possesses the greatest amount of experience in this connection and hence in what follows we shall discuss some examples of Austrian retarding structures [1].

With the object of protecting Muehlau, after careful weighing and checking all possible modes of construction, the first retarding structures were built in the years 1935 to 1941. The Muehlau retarding installation consists of eight wedges having an average height of 4 m and an earth core, 0.5-m thick concrete walls at the impact locations and mortar walls at the remaining surfaces; in addition, the facility contains four guidance installations of the same material. There are located in a flat stretch of the track having an inclination of 25-30 percent and at an elevation of 1,025-1,050 m above sea level. In addition, 200 m above the retarding structures in the narrow avalanche track, a wedge was installed as a preliminary obstruction. These concrete wedges were supplemented at 940 m above sea level by two arresting basins which are closed by arresting dikes up to 9 m in height and which serve to trap the parts of the avalanche which have been able to break through the retarding structures. This group of retarding structures seems to have been successful. The catastrophic years 1945 and 1951 brought severe avalanches whose principal mass was arrested by the structures. Smaller portions flowed over the obstacles but remained lying at the bottoms of the slopes. The concrete wedges cut the avalanche at an angle of 90°. Depending upon the nature of the snow, the effect was highly variable. In the case of heavy snow, the deflected portions of the avalanche maintained their direction over long stretches and were only deflected by means of new wedges. The looser the snow, the smaller was the deflection, and hence the smaller was the effect.

In laying out retarding structures, this fact should be taken into account. If a retarding structure must be installed at a great elevation above sea level where catastrophic avalanches with loose snow inundate the descent path, one cannot hope for the same success as that obtained at Muehlau where the retarding facility, supplemented by arresting basins lies between 940 and 1,050 m above sea level.

Above the retarding structures in Muehlau it was possible for a hill of loose debris to obstruct the avalanche up to a height of 11.0 m [sic]. Despite the fact that almost every year the avalanche passed over it, the fury of the avalanche was not sufficient to carry it off. It has the same effect as the expensive concrete wedges; in other words, it appears to be possible to replace the latter with significantly cheaper earthen mounds.

These ideas were taken into account as early as 1949-1950 in retarding structures for the Allerheiligenhoefe avalanche at Innsbruck. Fourteen earth mounds 3-4 m high in the form of truncated circular cones and five guidance installations were erected; on the uphill side they were surfaced with the stones derived from the excavation. The cones were placed checkerboard style close together so that there was no open lane in the fall-line. The cost was less than one-tenth that of an equally large concrete installation or mortar-masonry installation. So far as we are aware, these retarding structures have performed well.

In 1951, three large avalanches descended into the retarding structures; all of them remained in the construction area. The upper cones were buried to a height of several meters, the lowest row of cones remained free. Snow mounds formed at the obstructions slowed the following avalanches. About 100,000 m^3 of snow were restrained. In 1953, a powder avalanche descended into the structures and was split up; no damage was observable in the adjacent forest. It appears that in this case, the retarding structures also had a favorable effect upon a powder avalanche. Thus far, the cones have not been damaged, despite various avalanche descents.

The good results in Austria caused avalanche construction engineers in Switzerland to employ these methods under certain conditions.

In 1957, in order to protect part of the barracks area of Andermatt at the foot of the Kirchberg, eight blocks of concrete with earth back-filling were set up. The concrete walls are 4.0 m high and 5.0 m wide. The cost per block was 6,000 francs. Figure 1 gives a survey of the type and arrangement of installations.

In 1958, retarding structures were set up in Alpogli/Wilerhorn, in the Briezwiler Precinct (Bernese highlands) [2]. The avalanche starts on the south slope of the Wilerhorn, 2,004 m above sea level, the inclination amounts to 45^o-50^o. In Alpogli (1,440 m above sea level), the avalanche encounters a flatter slope with inclination of about 35-40 percent [about 20^o] which is closed off by a natural obstruction. In the last 50 years, avalanches on several occasions broke through this natural obstruction, partially destroyed the forest below, and invaded the village of Brienzwiler, 702 m above sea level. After the cutting of wild hay was discontinued (causing a marked increase in the sliding factor as a consequence of the long-bladed grass) the number of dangerous avalanches increased. Protective measures for the security

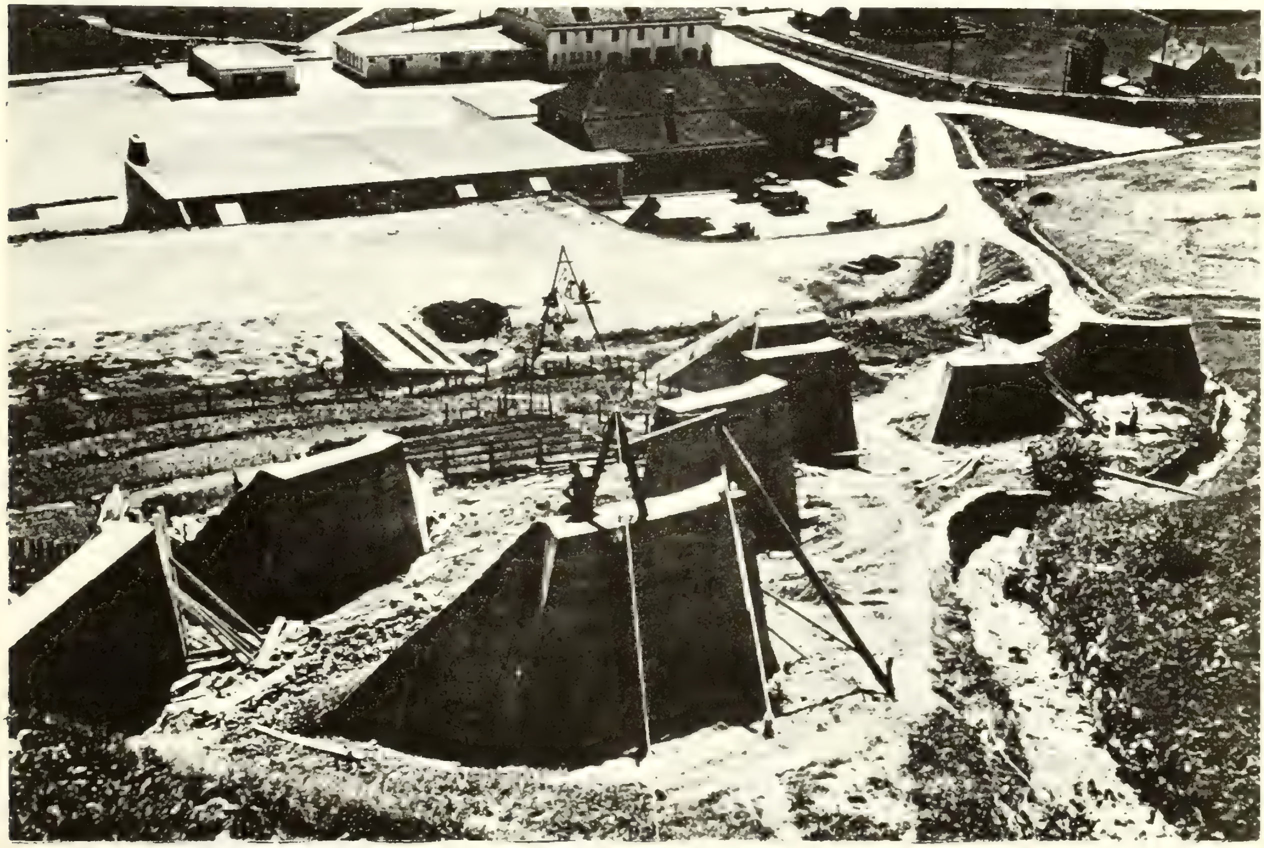


Figure 1. Retarding structures above the Andermatt Barracks (photo K. Oechslin).

of Brienzwiler became urgently necessary. A fully effective set of supporting structures in the starting zone of the type required would occupy an area of about 4.75 hectares. The slopes are sharply peaked and the foundation conditions are unfavorable for supporting structures; the cost of supporting structures is correspondingly very high.

A simple set of retarding structures does not offer reliable protection against the avalanches breaking out of the Wilerhorn, since the existing space is scanty and it is not possible to produce the required staggering in-depth of the retarding structures.

By using a combination of supporting structures and retarding structures, it was possible to take the most economically favorable safety measures. These construction operations are supplemented by reforestation wherever possible in areas totaling 2.2 hectares.

The Alpogli retarding structures with 23 retarding mounds and an arresting dike 170 m in length was installed with the best possible utilization of the terrain (Figure 2).

The cost of this project comes to a total of 790,000 francs. This is divided among the following types of operation: cultivation 50,250 francs, retarding structures 146,400 francs, supporting structures 478,000 francs, enclosures [fencing, etc.] 5,000 francs, access roads 18,200 francs, miscellaneous 33,000 francs, and provision for contingencies 59,150. The use of supporting structures alone would have required over 1 million francs.

In Alpogli, an economical solution for the protection of Brienzwiler was found by a combination of supporting structures, afforestation, and retarding structures -- to mention the principal measures.

As Figure 2 shows, the terrain is suited to retarding structures. The slope inclination at the lowest mounds is 6° to 17°, in the upper row it is 17° to 26° and only at the uppermost three mounds is it 26° to 30°. The uppermost limiting value of slope inclination for effective retarding structures amounts to about 12° to 15°, which corresponds to the minimum coefficient of friction of the flowing snow (compare B. Salm, Section 5.2). This inclination -- with the exception of the forward splitting mounds on Alpogli -- is not substantially exceeded in the cases of the retarding projects listed.

The height of the retarding mound in Alpogli, corresponding to the quantities of snow expected, has been set at 5.0 m and only the three uppermost mounds have a height of 4.0 m. The pressure of the avalanche masses upon retarding elements increases as the square of the velocity of the avalanche.

It is definitely true that the higher the retarding elements, the greater will be their effect. Hence, it would be desirable to install as many overdimensioned mounds as possible. The volume (V) of the conical mound may be computed as follows

$$V = \frac{h\ a\ b}{3}\ \pi$$

h = height of the mound (perpendicular to the slope up to the vertex of the cone),
a = half of the largest diameter of the elliptical base area,
b = half of the smallest diameter of the elliptical base area.

This formula constitutes an argument against overdimensioned heights since the volume increases as the third power of the height (a cone of 5.0 m height has, depending upon the terrain inclination, about the same volume as two cones 4.0 m in height). Excessive heights are therefore uneconomical, nevertheless, the cones must be high enough; the decisive factor is the expected flow heights of the avalanches (compare S. Salm, Section 5.2).

The installations in Alpogli are arranged in a checkerboard pattern with the intermediate spaces of the individual mounds being closed off so that no continuous alleys arise.

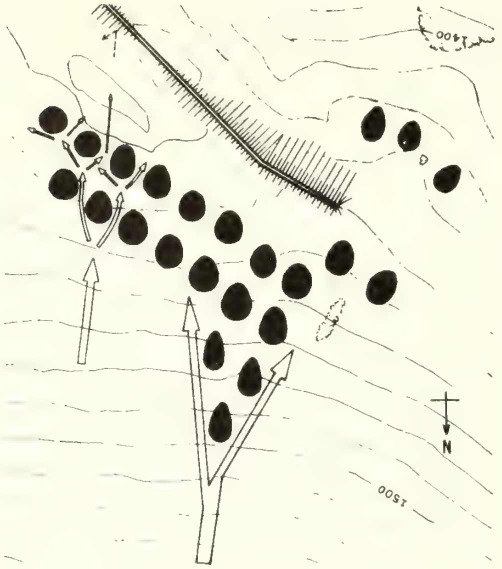
The intermediate spaces have been kept very small, with a value of 5.5 m or an axial distance from mound to mound of 20 m. This corresponds to the recommendations of the Austrian pioneers in the use of retarding structures.

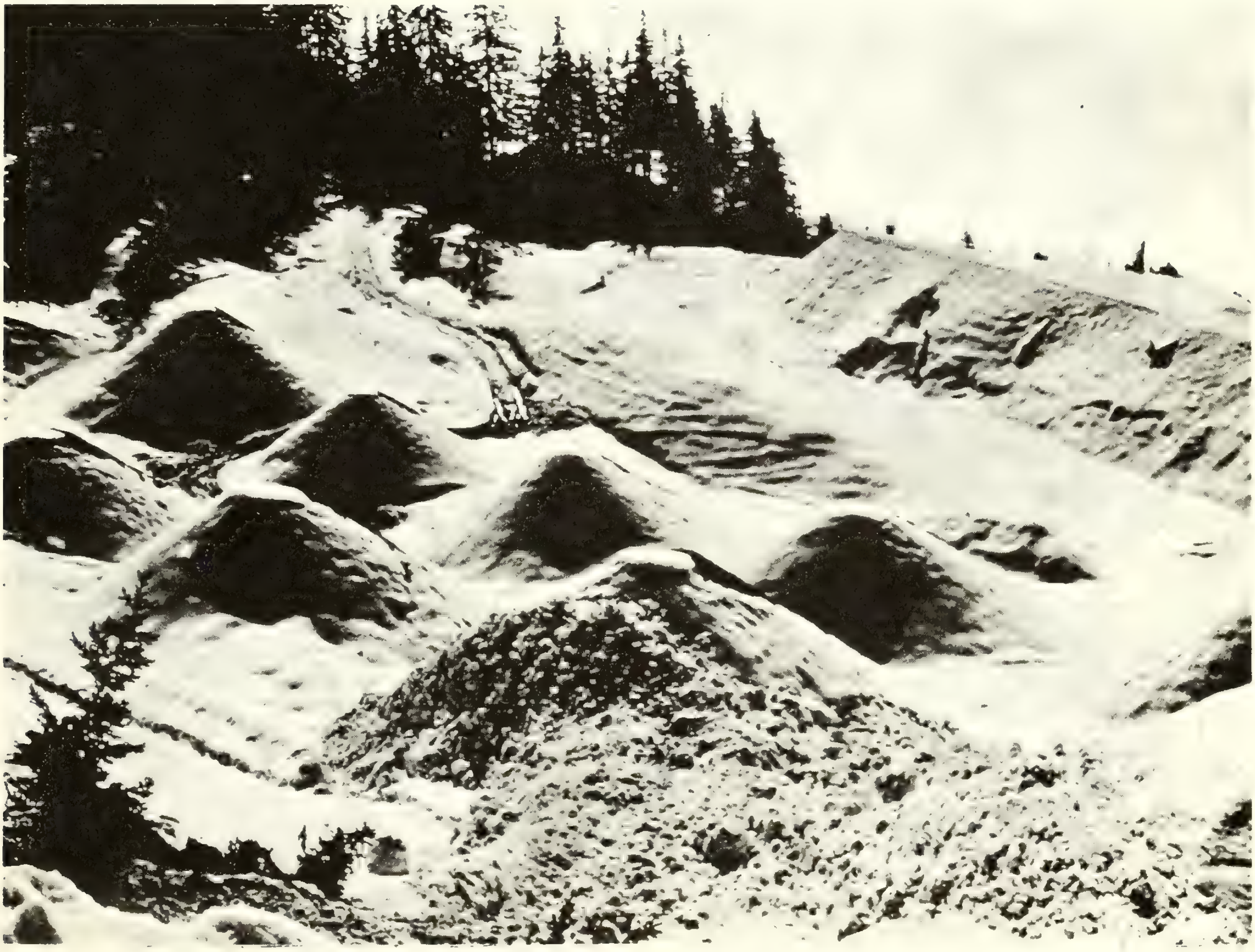
Size and cost: In Alpogli, the sizes of the 5.0-m-high mounds varied from 320 to 580 m^3, and this variation corresponded to the great effect of the slope inclination. On an average, the volume amounted to 427 m^3 and the mean cost per mound amounted to 2,067 francs.

Up to now, this project has proven itself, although on one occasion a powder avalanche traveled through it; in this case, nevertheless, there was a certain amount of retarding effect.

Another form of avalanche control structure is proposed by the VOBAG Company in Adliswil/ZH. The installations are designed for a load of 40 t/m^2 and slow avalanches by lateral deflection combined with a process of squeezing the snow masses between the open beams of the structure. Reinforced concrete is definitely weather resistant, but it is

Figure 2. Retarding structures "Alpogli," Brienzwiler (situation plan and photo W. Schwarz).





sensitive to shock and the stones and timber dragged along by avalanches constitute a great danger for this type of structure.

The effect of retarding structures upon powder avalanches has still been little investigated. In the case of this type of construction, model tests cannot be employed with the same possibilities of success as in the case of supporting structures. Observations of the various retarding structures will provide the best principles for future projects.

It is certainly true that not all possibilities for retarding structures have been exhausted. Depending upon the characteristics of the terrain, the slowing of the avalanche or the total dissipation of the avalanche energy can be transmitted to natural obstacles [sic]. This possibility is indicated by the example of the planned retarding structures in Reckingen; under the same favorable terrain conditions as those in Baechital/Reckingen, this possibility would surely be utilized elsewhere.

On the 24th of February 1970, a tremendous avalanche broke loose on the forward Galmihorn at about 3,300 m above sea level, and on the Hohen Gwaechte at 3,180 m above sea level. This avalanche claimed 30 lives in Reckingen at about 1,330 m above sea level and totally destroyed seven buildings.

For the immediate protection of the village of Reckingen and of the military facilities in Gluringen, there was created, in a first construction stage in 1970/71 a guidance channel about 530 m in length, having a mean height of 12.0 m and a width of 80 m. The calculations for the dimensioning of the guidance channel were provided by the Federal Institute for Snow and Avalanche Research, Weissfluhjoch/Davos. The deposited snow masses of the avalanche amounted to 280,000 m^3. The earth works of the dikes required 50,000 m^3 of earth at an expense of about 3.0 million francs.

In a second stage of construction, a road was built in the Baechital for carrying out the retarding project and in the starting zone of the Baechialp (not included in the retarding project). The length of the road was 12.5 km, the width up to the Baechital was 3.5 m, and from there into the starting zone it was 3.0 m. The cost thus far has amounted to 700,000 francs. In a third stage of construction, to be carried out in 1973/74, retarding structures are to be built in the Baechital against the avalanches from the Vordern and Galmihorn and the Hohen Gwaechte. Because of the high costs, supporting structures are acceptable neither on the Galmihorn, with a construction area of about 20 hectares, nor on the Hohen Gwaechte which has a construction area of 30 hectares. In addition, the soil conditions render an anchoring of the installations impossible (in part glaciers or rock debris and in addition much falling rock).

Planned retarding installations in the Baechital/Reckingen:

The avalanches from the steep slopes of the Vordern Galmihorn and of the Hohen Gwaechte encounter one another on a surface having an inclination of about 33° and an elevation of about 2,300 m above sea level. Between 2,100 and 2,200 m the mean gradient is 15-17 percent and from there to 1,980 m above sea level it averages 22 percent. Below an elevation of 1,980 m the track again becomes somewhat steeper; the gradient amounts to about 35 percent. The inclination is not uniform; short steep portions are followed by flatter stretches.

From the junction of the avalanches at about 2,300 m above sea level down to the canton highway (residential region), the length of the track is 3.6 km with a mean inclination of 33 percent. The inclination conditions are therefore very favorable for retarding structures, particularly in the flat regions between 1,980 and 2,200 m above sea level. The calculations according to the formula

$$H_D \geqq \frac{v^2}{2g} + H_L + H_S$$

(compare B. Salm, Section 5.2) give a height of 28 m for an individual arresting structure at an elevation of 2,000 m above sea level. The compression force of the avalanches at this location amounts to 15 t/m^2, according to the formula

$$p_n \approx \frac{\gamma}{g} v^2$$

(compare M. de Quervain, Section 5).

The terrain which flattens locally to an inclination of about 15 percent in this region is probably very favorable. But an arresting dike with this computed height, having an uphill slope of 1:1 and a downhill slope of 4:5 requires a width at the foot of the dike (crown width of 2.5 m) of about 70 m. The volume of a single arresting dike with inclined base [Fallboden], would be too great and consequently uneconomical. After close study of the terrain, the retarding facility was planned as follows (preliminary project):

At an elevation of 2,200 m above sea level the flattening of the terrain (slope inclination 15-17 percent) permits the erection of a deflection dike which diverts the avalanche at a sharp angle toward the right flank of the valley. The height of the dike is planned to be from 10 to 12 m. As Figure 3 shows, the cliff rocks are best suited to the dissipation of the energy of the avalanche. This energy dissipation is therefore intended to be accomplished for the most part by natural obstructions -- projecting rocks and sharp notches. Since above these rocky walls no aggregations of snow are possible, no additional masses of snow are released by the diverted avalanches.

Below these rocky projections, at a distance of 350 to 400 m, retarding mounds are provided in the usual shape from 4 to 5 m in height, with giant blocks of rock forming a substantial constituent of the retarding facility. About 200 m below the mounds, at about 2,000 m above sea level, there is planned an arresting installation (inclined ground and arresting dike having an effective height of 12-15 m) in order to trap the portions of the avalanche overrunning the retarding structures. Despite the fact that this project with deflection dike, retarding mounds, and arresting installation requires smaller mass displacements than the facility involving a single arresting installation of 28-m height, its effect will probably suffice to stop avalanches before they reach the canton highway (residential region). The first observations of descending avalanches will show whether these assumptions are correct. The project is still not completely worked out; the probable costs, however, should not exceed 4 million francs.

In order to achieve an approximately equivalent protective effect for Reckingen as that provided for the planned retarding facility, supporting structures on the Hohen Gwaechte and on the Vordern Galmihorn, at a total area of 50 hectares, would require an expenditure of at least 25 million francs (50 hectares x 500,000 francs/hectare). In addition the protective effect of the supporting struc-

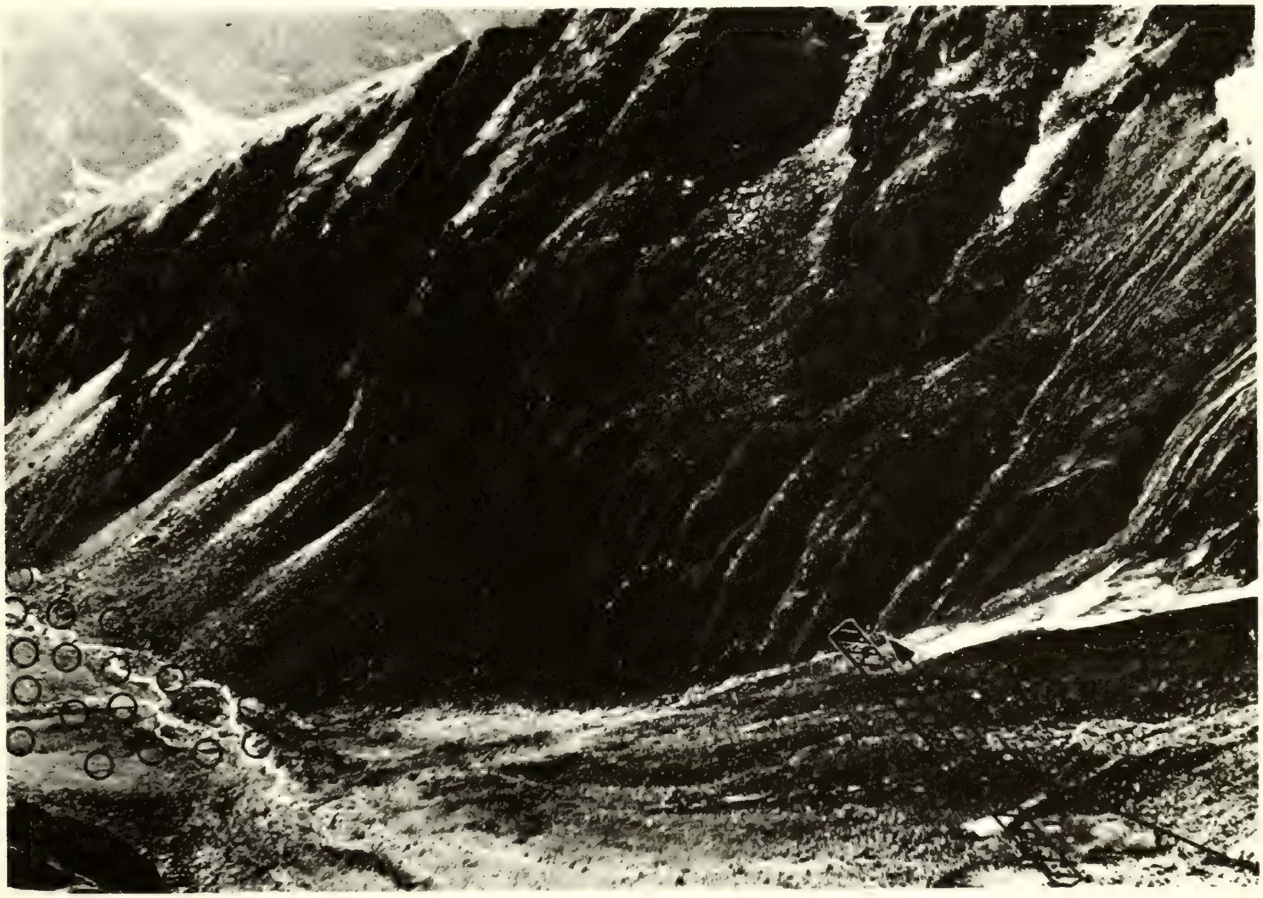


Figure 3. Planned retarding structures in Reckingen; deflection dike in the foreground right, left retarding mounds (photo J. P. Graf).

tures would be very dubious since even the greatest installations hitherto constructed would very probably be buried in snow, so that the danger for Reckingen and for the military facilities in Gluringen could not be satisfactorily reduced.

In the case of Reckingen, a retarding facility is distinctly safer and at the same time essentially more economical. With increasing mechanization and with the sharp increase in the cost of manual labor like that required for supporting structures, the price difference between this type of construction and retarding installations gets ever larger. In addition, personnel are becoming ever more difficult to obtain, especially for remote and climatically unfavorable regions. The reasons for this are generally familiar.

Hence, for new construction projects, all possible methods of protection against avalanches should be thoroughly examined and one should not only look for a solution -- although tried and true -- by means of a modern avalanche structure in the starting zone.

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XII. EVOLUTION OF AN AVALANCHE STRUCTURAL CONTROL AND AFFORESTATION PROJECT

(Alexi Sialm, Disentis)

1. Retrospect

After the devastating avalanche winter of 1951 which cost the lives of 96 people and caused damage to forest and fields, to buildings, and traffic arteries running into the millions, officials and forestry people turned with a will to the planning and realization of avalanche protective measures. A large number of completed projects testifies to the extraordinary efforts of the last decades. The struggle with the forces of nature is, however, a permanent struggle. Therefore, it is also not remarkable that today there are still numerous structural control projects awaiting realization. In this connection, it should be emphasized that modern man manifests an increased need for safety in all departments of life. The consistent expansion of all forms of social insurance and the demand for public pension systems are testimony of this. In mountain communities, this need expresses itself further in the desire for increased security in the home, on the road, and by rail. But protection against the forces of nature also corresponds to a modern conception of economic development which aims at regionalization and centralization.

2. The First Steps

The first steps toward clarification of an avalanche structural control project are normally undertaken by community officials together with forestry organizations. Frequently a common reconnaissance takes place in which general technical, legal, and economic aspects of the prospective undertaking are discussed. As a result of these joint conversations, a general preliminary project is submitted by the district forestry office to the cantonal forestry office and the Federal Forest Inspectorate (OFI). On the basis of this general preliminary project, which contains only summary data regarding the purpose of the project, the installation to be provided, the anticipated operations schematically diagrammed in plan view, and the approximate prospective costs, there is then a review on the part of the federal and cantonal forestry organizations in conjunction with the representatives of the Board of Works. The most important result of this review is the decision as to whether the proposed project can be undertaken by the Federal Government and the canton or not. Further, it is determined on the basis of this reconnaissance whether the building project should be immediately planned as an urgent program and subsequently carried out or whether it should be postponed for some weighty reasons. Naturally, there is also a discussion of technical questions with regard to the building project and the building performance. In many cases, also as a result of this review, the Federal Institute for Snow and Avalanche Research, Davos/Weissfluhjoch (EISLF) is commissioned to provide a professional opinion. On the basis of all these discussions as well as of any possible professional opinion from the EISLF, a final project is worked out in accordance with the "Specifications of the Federal Department of the Interior for Forest Projects and Their Support by the Federal Government." For avalanche structural control and afforestation projects of great magnitude whose performance extends over a long period of time, it suffices at this point to work out a general overall project. In such cases, detailed projects must be set up within the framework of the overall project; these detailed projects must be approved by the OFI before the beginning of construction. The final project (for the formulation of which various further discussions with the cantonal forestry office and with the OFI with regard to financial and technical detailed questions may still be necessary depending upon the importance and the financial and architectural extent of the project) is submitted, after its final review, to the cantonal and federal subsidizing officials for approval and assurance of subsidies.

3. Technical and Economic Prerequisites

A prerequisite for the planning of any type of structural control is danger to a locality, a road, a railroad line, or the restoration of endangered protective forests. With regard to the various possible methods of structural avalanche control, we refer the reader to the article by Hans Oppliger on avalanche protective measures in this same publication.

Theoretically, it is possible to deal with almost any danger by means of some measure or combination of measures. Various types of construction, depending upon the topography and situation of the objects to be protected, are, however, associated with different costs. An economic weighing is therefore of decisive importance. Nevertheless, the economic point of view ought not be the only decisive factor. At the center of all considerations is man, his security, his endangered environment. Thus, economic considerations should only play a role in the evaluation of measures which are of equal value but different in cost. In this connection, it is worthy of mention that resettlements in the sense of dislocations of entire villages or parts of villages have, up to now, never been carried out. The residential uprooting associated with such resettlement can hardly be sponsored today with public resources. But the situation is somewhat different in the case of a resettlement of individual houses within the same settlement area.

In any project, attention must be given to the following considerations: deflecting structures and galleries represent direct methods of protecting an object. But such measures often lack total-economic and total-planning aspects. As a rule, they only protect individual objects. With structures in the starting zone of the avalanches in combination with afforestations, one usually achieves an integral improvement, in contrast to measures that directly protect objects. The former measures guarantee desirable avalanche protection, contribute to the growth of forests, to improved yields and to the acquisition of recreation space while at the same time often meeting the needs of landscape protection. Some projects and professional opinions in recent years have demonstrated that in various places supporting structures together with afforestations are able to sustain a cost comparison with galleries and deflection constructions. But from the total economic point of view, the former are also interesting because the starting zones and afforestation areas are in general made accessible by means of a road network which as a rule leads from settlements in the valley far up into the control area. Thus, frequently both agriculturally important and forest regions are made accessible and more easily reached by the general public.

Undoubtedly, construction and afforestation projects, in addition to their primary tasks of protection and safety, also result in secondary accomplishments such as opening up and creating additional recreation regions. In the Swiss midlands, the communities often encounter great difficulties in the procurement of land for public purposes. Therefore, whenever in mountain cantons new land areas can be acquired thanks to avalanche control and afforestation projects, this can only be an advantage. The flat country and the mountain cantons today more than ever form a common working, free-time, and recreation unit. In this sense it should not be too difficult to promote avalanche construction projects and afforestation projects also from the aspect of space planning.

4. Legal Principles

The legal prerequisites to financial support of structural avalanche protection measures on the part of the Federal Government are described in essence in articles 37, 37^{bis} [second part of article 37], and 42 of the "Federal Law Respecting the Federal Supervision of Forest Police." It may be asserted that this federal law in great measure promotes avalanche safety measures and thereby to a remarkable degree contributes to the total economic benefit of our mountain communities. In addition, we refer the reader to the discussion, by W. Bauer, of federal subsidizing procedures in this same number.

5. Various Phases of Planning and Their Time Requirements

It may be of interest to laymen to get some idea of the course of an avalanche construction project and afforestation project from the time of the first reconnaissance until the first spadeful of earth [is turned]. The complexity of avalanche construction projects excludes simple schemes and cheap household recipes. It should also be evident that a small and simple project can be set up in a relatively short time and normally will not require more than about 1 year while, on the other hand, a larger more complicated project requires more time expenditure for planning and execution.

In the planning, one distinguishes the following phases:

a. the general preliminary project -- preliminary examination;

b. final project -- first spadeful of earth.

5.1 General Preliminary Project -- Preliminary Examination

As has already been mentioned at the outset, each construction project must be announced to the OFI in the form of a general preliminary project. This very concise preliminary project, for which no detailed field operations are yet necessary, forms a first foundation for the review which must be carried out. Since avalanche construction projects by their nature are usually very urgent, the preliminary examination as a rule also takes place very soon after submission of the general preliminary project. To the extent that it is not only forest interests which are involved, which is very often the case, representatives of other professional services of the Federal Government and of the canton who might be interested in the project are invited to the preliminary examination if this invitation seems necessary. The review in the terrain itself serves for a preliminary clarification of the entire project and provides the foundation for further detailed project work.

5.2 Final Project -- First Spadeful of Earth

On the basis of the discussions occasioned by the previously mentioned review, work now begins on the final project. This will in itself be a detailed project when the building project is of small extent and of short duration. When the building operations are of great extent and of long duration in performance, this can be a general project which will be followed, after its approval, by the corresponding partial detailed projects. But even the general project must concern itself very particularly with details regarding the nature and manner of the construction, of the types of structure to be provided, the extent of the structural installations, of the nature of the access provided, and of the construction transport to be employed, etc. Here the thorough and comprehensive processing of the project in the field and in the office begins.

Since the planning of supporting structures in the starting zone on the one hand requires operations in the field, on the drawing board, and at the computer and, on the other hand, presupposes an observation of the avalanche slope over a number of years, the working out of a project is accompanied by certain difficulties. In this connection, it should be mentioned that many district and regional forest officers since the avalanche winter of 1951 have collected very valuable documentary material which contributes substantially to the solution of avalanche engineering problems in a reasonable length of time.

The procurement of cartographic documentation is rather time consuming. In our mountain communities, we must often be happy when a survey plan is available to a scale 1:10,000. This permits a rough preliminary clarification but no more. To the extent that no better documentation is available from other sources, one is compelled to set up plane-table surveys of the construction region or, when recent aerial photographs exist, to have these cartographically evaluated to the desired scale. Recently, the orthophoto plan [aerial photos with the scale corrected for slope] has offered us a very valuable aid for the layout.

For each construction project, snow observations are an indispensable foundation. Unfortunately they are often not available, so that one must get along with assumptions, which perhaps it may be possible to supplement somewhat with observations of neighboring regions. Therefore, it is indispensable, from the moment of commitment to avalanche construction, to carry out observations in the construction region. In most cases, one thereby obtains, prior to the beginning of the actual construction operations, some documentation which is valuable for the detailed design. Naturally these observations must continue to be carried out during the entire construction time and also later. To the extent that it appears necessary, a professional opinion of the specialists of the EISLF can be obtained. In the case of large projects, this professional opinion is as a rule requested by the OFI.

A point which can entail unpleasant delays is the acquisition of land. To the extent that the construction region involves public ground, this is a simple matter. It becomes more difficult and time-consuming whenever private land must be obtained, especially in the case when a satisfactory agreement is not reached and steps must be taken toward expropriation.

In many cases, the design of the final project is distributed among the cantonal forestry offices and the OFI for comment in order that possible suggestions and criticisms may be taken into account. After cleaning up all still open questions, the project can be submitted to the Federal Government and the canton for subsidizing and this as a rule does not require too long a wait, and thereafter work can begin on the construction. In very urgent cases it is even possible, prior to the approval of the subsidizing authorities, to obtain a preliminary construction permit in order that the project operations can be commenced without delay.

From the preceding, it is not difficult to see that it is hardly possible to provide binding data regarding the time consumption of an avalanche structural control and afforestation project from the moment of the preliminary examination to the first spadeful of earth. In the most favorable case, this may be 1 to 2 years, but under more difficult circumstances, it can be many times that.

6. Project Documentation

In accordance with the "Specifications for Forestry Projects and Their Support on the Part of the Federal Government" dated 1 September 1961, for each project at least the following documentation must be supplied:

a. A technical report,

b. A preliminary cost estimate,

c. Plans, profiles, standards,

d. Aerial photographs, photo documentation,

e. Construction statement.

The aggregate of all project documents serve not only to produce subsidy assurances on the part of the Federal Government and the canton, but rather they represent for the project planner, the forest engineer supervising the construction, and in particular, the community officials a comprehensive presentation of all questions relating to the project. They represent a well-thought-out basic conception which is designed to eliminate incorrect investments and incorrect planning. The following table of contents of the technical report of an avalanche and afforestation project gives an insight into such a documentation.

"Crap-Stagias" Avalanche Structural Control and Afforestation Project

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1. General Remarks
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8. Billeting and Equipment Storage
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10. Setting up the Preliminary Cost Estimate

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    10.2 Cost Subdivision by Position

11. Project Execution and Building Supervision
12. Duration of Project Execution

Graphics

Average Precipitation 1936-45
T [temperature] Monthly Average 1864-1900
Scheduling Plan and Financial Requirements, 1971-1982-1995
Form A (Technical Data)
Form B (Cost Estimate)

In many construction projects millions of francs are involved. Even when large contributions have been provided by the Federal Government and by the canton, the annual allotments of what are often hundreds of thousands of francs represent no small financial burden for the Board of Works. Therefore, it is necessary to work out with each project a so-called scheduling and financial requirement plan (Table 1). This is intended to facilitate the overall financial planning of the community. It is also desirable, especially when one is operating under a master plan, to set up appropriate network plans. These constitute a great organizational aid.

We refer the reader to the discussion by F. Pfister of operations engineering aspects of avalanche construction, in this publication.

From what has been mentioned above, it is evident that the project papers which have been described constitute a comprehensive documentation and source of information which, together with the financial requirement plan, scheduling plan, and possibly also with the network plan permit the subsidizing authorities, the construction supervising forest engineer, and in particular also our precinct officials to have a complete insight into the entire complex of questions relating to the construction project.

7. Project Execution and Project Duration

The specifications, already mentioned, for forest projects and their support by the Federal Government prescribe that the construction supervising forest engineer shall annually submit a construction program to the OFI. The partial detailed projects which follow up the general construction project are a constituent of this construction program. To the extent that the Board of Works does not encounter any special circumstances such as a labor shortage, financial difficulties, and so on, the annual construction program is in substantial agreement with the long-term scheduling and financing plan.

An avalanche construction project and afforestation project usually include a great number of operations such as control structures, afforestations, drainage operations, construction of access roads, protection of the afforestation from grazing and wild animals, etc. It is only rarely possible to carry out all these operations simultaneously, more commonly the work scheduling requires, as shown clearly in the attached scheduling plan (Table 1), that the timing be staggered. In addition, owing to the weather conditions at these high elevations there is a short annual work period of scarcely more than 100 days in summer. The relatively small volume of work possible under these circumstances, particularly in the case of large projects, compels one to accept a long overall project time. Particularly with afforestation, one must reckon with very long periods of time. It is well known that afforestations in the region of the upper tree line are associated with very great difficulties.

In view of all these difficulties in the construction process, for the practical execution of an avalanche construction project and afforestation project one must count on long time intervals. In the best case such a project, if it is of small extent, can be realized in about 8 to 10 years. But large, difficult construction and afforestation projects can require decades.

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Table 1. "Crap-Stagias" Avalanche Structural Control and Afforestation Project, Scheduling and Financial Requirement Plan 1971-1982-1995
[In 1,000's of Swiss Francs]

Designation of Operations	Total Amount	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983-1995	Contingency
Forest Plantings	280	1	5	5	10	20	20	20	20	20	20	20	20	99	
Avalanche Structures:															
Permanent	3072					400	450	500	550	600	572				
Temporary	1107	70	40	10				100	50	50	50	200	250	287	
Access:															
Roads	1065	250	280	280	255										
Patrol Paths	45	5	5		10	10	15								
Grazing Protection	19.5		5	1	1	1	.5	.5	.5	.5	.5	.5	.5	8	
Land Purchase	10		10												
Miscellaneous (Hut = H)	434.2	90	44.2	15	H80	20	20	20	20	20	20	15	15	55	
Contingency	467.3														467.3
Annual Financial Requirement		416	389.2	311	356	451	505.5	640.5	640.5	690.5	662.5	235.5	285.5	449	467.3
Total Financial Requirement	6500														

XIII. MANAGEMENT ASPECTS OF AVALANCHE CONSTRUCTION PROJECTS

(F. Pfister, Brigels)

1. Managerial Development

It may be generally asserted that the treatment of managerial problems lagged behind the technical development which has been described. To be sure, in various articles, attention has been drawn to the unavoidable necessity of taking economic principles into account in solving technical problems. Under the impression that avalanche construction projects must necessarily be erected at the cost of great financial sacrifices, nevertheless an attempt was made in this area of the construction process to keep techniques of organization and rationalization in the background.

Nevertheless, it should also be noted that the theory of construction management has only recently been accorded the significance it merits. It is precisely in the building trade that utilization of managerial knowledge is especially important. Both of these statements are based upon the special characteristics of the building trade as they have been described by Soeser [7]. Special features, such as single part production, contractual production, and building site production, more closely described by Beste [1], must be given special attention in avalanche construction. But it is a mistake to oppose managerial studies out of a fear of the effects which have been mentioned. In recent years, the consequences of these negligences have begun to show themselves. Because of the special situation in the building market, there has often been no relation between the offers and the primary costs. There were extreme differences between the bids. In the absence of the necessary documentation, the building administrators could evaluate the price development only with increasing uncertainty.

Hence, it becomes urgently necessary to deal with the following man-problems, listed in a concise form:

a. effective cost surveillance by means of a practical auditing system;

b. the effect of construction features, weather, operational structure, and other factors influencing cost;

c. effect of the timing and planning configuration of a project upon its cost;

d. efforts to introduce efficiency into the engineering process.

Under the guidance of Prof. Dr. H. Tromp and the vigorous cooperation of the "Working Group for Avalanche Construction" I had an opportunity to investigate some of these problems [5]. This experience has given rise to proposals for the improvement of planning, performance, and surveillance of avalanche construction projects, which will be briefly described and supported in what follows.

2. Critical Consideration of the Existing Auditing Procedure

The principles of cost accounting are outlined by Fein [4] as follows: "Cost accounting has the task of determining costs correctly and completely and of distributing them. Only in this way can the two tasks of uncovering sources of loss and of correctly pricing individual products be accomplished." From this there arises the possibility of estimating, in the preliminary cost accounting, the prospective costs for a particular product and of checking and correcting this estimate in the later cost accounting. In the management of avalanche construction projects, it will be possible to take into account all the conditions which have been mentioned only when the building operations are conducted under in-house control and -- with limitations -- when they are conducted under the control of an entrepreneur. The performance of the project is usually let out under contract so that the accounting can be carried out only with respect to amounts of performance and prices bid. But if one desires to know not only which expenditures have vouchers to cover them but also to have information regarding the economics of the activity, then in addition there must be an operating cost statement.

The auditing procedure desired by the Federal Government does not provide any systematic division into types of cost and departmental costs. The auditing specifications prescribe a division in terms of the varieties of work (Form B), but these are inadequately described and unequally applied. Since, therefore, it is scarcely possible to distribute the costs, according to the cost-origin principle, precisely over the performances of the operation, preliminary cost accounting and later cost accounting become unrealistic. This finally led to the uncertainty in evaluating offers mentioned at the outset, while at the same time it was no longer possible to check the justification associated with demands for particular performance achievements.

From the preceding consideration, it follows that it is a central problem of cost studies to work out an effective auditing method. In addition, the operating cost statement, built upon the three levels of cost type auditing, departmental cost auditing, and cost carrier auditing, must be designed while taking into consideration various types of performance, modes of construction, work systems, etc.

But in order to be able to assign as many direct and indirect costs as possible to parts of the operation which are delimitable organizationally, operationally, and cost-wise, the operations of an avalanche construction project were contracted out for 3 years to the control of an entrepreneur. It was possible to supplement and solidify the evaluations of these latter operations, in the mentioned investigation, by means of additional data collected in six other projects in the cantons of Uri, Bern, Graubuenden, and Tessin.

In order to determine the various cost types according to cost department, it was necessary to construct a well functioning reporting system. Corresponding to the significance which is attributed to the determination of costs and performances, in the following section there will be an account of the problems connected with this process and of the routes which have been taken toward solving these problems.

3. Reporting System for Determining Costs and Performance

The reporting system is intended to make it possible to survey the building process, to carry out control checks, and to make necessary decisions. In addition, most of the data serve the purpose of auditing with respect to all personnel and levels of authority participating in the construction. For the solution of these problems, the reporting system must supply the necessary information regarding initiation of operations, consumption of operating resources and of raw materials as well as the job progress. If one is not to have merely a few randomly jotted pieces of data, but if instead all statistics are to be true, meaningful, and unambiguous, then it is specially important to limit the scope of the questions while outlining the questions exactly. In constructing a report procedure which can satisfy the enumerated requirements, special attention should be given to the aid called "Construction Operations Key" (abbreviated in the following as BAS).

The BAS is nothing but a list of all existing construction operations. Up until the present, construction operations have been predominantly subdivided from the point of view of performance. The various performance lists concern themselves with individual contracts and products which are subdivided by positions in program execution segments. The subdivision is thereby adapted to the requirements of the contract consignor so that the same operations appear under different position numbers and ordinal designations.

Instead, the BAS bills on the basis of a subdivision of operations. This gives rise to a constant system of subdivision for the purpose of the operating cost statement, cost accounting, and especially for planning and organization. This can be adapted to the various conditions and types of contract in other projects without thereby abandoning the possibility of interoperational comparisons. If descriptive documentation and performance measurement are also arranged in accordance with the BAS, then a system is created which will give the construction supervisors all necessary documentation for carrying out their managerial tasks.

Every type of operation in the BAS receives a number which is constructed in accordance with a decimal classification system. In the appendix to my dissertation [5], the BAS, set up for the studies which have been mentioned, is reproduced together with precise description and delimitation of the individual components. The sequential order and grouping have been adapted to the development of the auditing procedure and the requirements of network planning technology.

4. Operating Cost Statement

The operating cost statement is carried out tabularly on operating cost statement sheets for which, in general, the abbreviation BAB is employed.

Its principal purpose is to derive the differentiated additional payment and additional charge figures for cost accounting. Here it must be assumed that, by means of this cost accounting, a double object is pursued: On the one hand it is intended that by means of the cost carrier auditing (under the condition of a correct and complete cost determination and cost assessment) there should be a cost accounting of the costs per performance unit for erecting the installations, separated with respect to systems. On the other hand, the departmental costs should be delimited in such a way that for checking and evaluating the bids it will be possible to compare subsequently cost accounted cost values corresponding to the unit prices.

4.1 Cost Type Auditing

In cost type auditing, all costs of the operation are collected. In contrast to subsidy accounting, the costs for preliminary operations in completed or subsequent building programs are to be included and excluded respectively. The corrected costs to be charged are charged immediately to the cost carriers as direct costs or included as indirect costs in the auxiliary cost and principal cost locations which in turn are passed on to the cost carrier, if possible without keying (which guarantees only an approximately correct distribution). This principle can be extensively followed with the aid of the BAS and the rule that all overhead cost vouchers should be immediately accounted with the originating cost department.

In the previously mentioned investigation, the cost types have been grouped under the following generally valid concepts: material costs, equipment costs, rent costs, personnel costs, foreign costs, write-offs, repair and maintenance costs, and other expenses. For a discussion of the individual cost types and their evaluation in special auditings, the reader is referred to the literature [5].

4.2 Cost Department Auditing

A subdivision of the operation into components which represent only locally or functionally delimited areas does not satisfy the requirements of cost department auditing. These requirements consist, among others, of acquiring documentation for the evaluation of bids. In order to be able to compute the unit costs for performances of similar type, the costs should be combined together in operationally significant areas from the point of view of accounting technique.

The auxiliary cost has been separated from the principal costs which have been subdivided into the two production stages: installation substructure and installation superstructure. This is because the auxiliary costs contribute only indirectly to formation of the cost carriers.

The question of the distinction of cost types and the possibility of their being distributed over cost departments played an important role in setting up the cost departments. We have already referred to the decisive function of the BAS in this connection. Despite the close relationship between BAS and the cost department list, these two concepts are, however, not to be equated. The BAS goes further in the direction of subdivision on the basis of additionally required data for cost accounting, operations studies, organization planning, and interpretation of results than does the cost department list which primarily divides the total performance into subperformances. Different positions of the BAS have therefore been combined for the cost department auditing. In contrast to the BAS which creates only a distribution basis for operation-referred costs, the cost departments include all cost types.

4.3 Cost Carrier Auditing

The overall accounting of the performances accomplished in a period, divided according to cost carrier groups, is accomplished in cost carrier auditing. By means of it, it is possible to calculate the costs per unit, i.e., carry out the cost accounting. Additional charge, assessment, and additional auditing of the cost departments are connected with the cost accounting. Here all the procedures are used which will be briefly described in the following:

Division cost accounting is applied in the case when a uniform type of performance is set up. Although in an avalanche construction project many different types of installations are erected, it was not possible to take these differences into account in the first investigations. The cost sets for the cost carriers were obtained by division of the sum -- formed from the direct costs and all additional charges -- by the corresponding summed installation lengths. By the same method, all unit costs were calculated for those component performances which were delimited in terms of cost departments. The division cost accounting is preceded by the assessment of the cost departments. This takes place predominantly in the form of an additional charge upon the direct costs, in other words from the point of view of additional charge cost accounting.

The assessment of the cost departments can, however, in individual cases also be carried out by means of key quantities and follow the principles of equivalence-figure cost accounting.

5. The Results of Collecting Cost Statistics

The accounting carried out according to the preceding principles during the several years of investigation in various construction projects produced the following highly compressed results:

Among the cost type groups, personnel costs constitute by far the greatest portion, with over half the total cost sum. Avalanche construction projects are still very work-intensive in comparison with other construction operations. The portion of the cost sum consisting of material costs still clearly lies below that of the personnel costs despite repeated use of prefabricated elements.

With respect to cost departments, almost half of all costs must be assigned to the substructure, where in particular excavation and concrete pouring of the foundations were of decisive significance.

The cost accounting of the unit costs for the suboperations included in the cost departments forms the basis of auditing the price offerings made by the entrepreneurs and for bid evaluation on the part of the construction administrators. The basis of this cost accounting consists of the measurable units of performance which are accomplished in the individual departments. The costs calculated for these units in the BAB are composed on the one hand of the cost types which are included in the cost departments, and on the other hand of the assessed costs of various auxiliary departments.

The assessment must be regulated in accordance with the construction site organization and is to be adapted to the account documentation. By means of the investigation, it was possible to derive the empirical figures for the additional charges to the department costs associated with the various component operations.

The results are based only upon cost statistics in individual projects. Nevertheless, it was possible to establish that the relative shares of cost types and of auxiliary cost department additional charges are only slightly influenced by the various conditions and project circumstances.

The situation is different for the absolute values of the unit costs, whose dependence upon the building market, upon the state of employment, upon the size of the operation, and upon the building program must be taken into account.

As an essential result of cost statistics gathering, the significance of personnel costs has been emphasized. In comparison to the significance of operation-referred productivity, the effect of the uncertainty factors which have been enumerated is slight. Therefore, by means of an additional determination of work times in six other constructions, there has been derived the documentation for inter-operational comparisons of work-referred productivity. This also provided data regarding the effect of the most important operational conditions upon the cost configuration. These conditions may be subdivided by combining effects in the domain of operational quantities (for example, of factor quality, of factor prices, et al), the domain of the peculiar characteristics of the object constructed (local transport and building site transport, degree of difficulty, structural features, etc.), and into the domain of production sequencing. Out of this multiplicity of influences the peculiarities of the building sites which are significant for the cost configuration are selected and in particular the cost functional-dependencies of various building features are analyzed.

With these general indications of the important relationships existing between working time expenditures and construction features, it was necessary to close the investigations of cost effects. It is true that still further effects are influential in determining the construction price and the construction costs. But they are of variable significance in the different building sites and must be investigated from case to case by means of further analyses. With the restrictions which have been mentioned, the effects of the most important operational conditions upon the cost configuration of a project can be inferred from the cost statistics which have been gathered. The additional time measurements in the domain of work-referred production furnish guiding values for adapting and transferring the results to other construction objects, while taking into account the special peculiarities of the building sites. These then are the principles of a minimal cost auditing which can in practice be carried out without great additional expense.

6. Cost Functions

Attention has been drawn to the problems associated with the cost accounting and the legally prescribed cost surveillance of avalanche construction projects. By means of detailed investigations of several building programs in one project and of additional installations in other projects, possibilities have been uncovered for improving the cost accounting. The developed cost accounting system can be introduced not only in a particular project but by adaptation to conditions of various sorts can also be introduced into other projects. In the event that the system is interpolated into the bookkeeping of construction enterprises this should give rise to no problems. But for lack of time and assistant personnel the construction administrators will usually find it impossible to carry out completely comprehensive analyses, in the manner shown, for the individual building programs.

If ever the cost influences of the specific circumstances of an avalanche construction project are investigated in their details, it will subsequently suffice for the construction administrators to know, for the purpose of cost surveillance, the most important cost functions and hence the order of magnitude of the building prices with reference to the principle of reasonableness [or "principle of suitability"]. The development of the cost functions and their significance for cost surveillance is described in what follows by means of an example and thereby simultaneously a proposal for a minimal cost accounting is described.

Cost accounting, account documentation, performance determination, and accounting are constructed in accordance with the operation divisions of the BAS. Thereby the auditing documentation is at the same time subdivided from the point of view of cost department divisions and cost carrier divisions. In order to set up the preliminary cost estimate and to evaluate submitted offers, therefore the cost department unit costs are calculated in a first step. As follows from the results, in this connection, of the investigations which have been mentioned, the unit costs are composed for the most part of the principal costs collected from the cost types and of an additional charge to the assessed auxiliary costs. The general observations implied by the results may be summarized as follows:

a. The share of the total department costs which consist of personnel costs is extraordinarily high and amounts on the average to about 50 percent.

b. Taking into account effects of various construction features, the ratio between the share consisting of personnel costs and the shares of the remaining types of cost to the department costs for all building programs and building segments displays a clear constancy.

c. If one evaluates the ratio of the auxiliary costs department additional charges to the department costs then these ratios are found to deviate little from one another in the 3 years of the investigation.

Taking these facts as a basis, cost functions can be constructed for the purpose of calculating cost department unit costs. Here the personnel costs form the reference magnitude for which one must make use of the work coefficients which are determinative in the calculation of such personnel costs. In the ratio to the personnel costs, the remaining cost types are added and in this way the direct department costs are obtained. In order to derive the total departmental unit costs, finally the auxiliary department costs are added to fixed percentages.

The minimal cost accounting described may now be explained by means of the example of the foundation excavation operations and assembly operations (price base 1965/66).

a. Foundation excavation

On the basis of preliminary investigations a rock quota of 70 percent is assumed for the calculation.

The investigation gives for the excavation work coefficients of 2.8-4.3 hours/m^3 (earth excavation and rock excavation). If one takes the ratio of these values to the rock quota, then a guiding value of 4.2 hours/m^3 may be derived from the results. Under the assumption of a factor price of 9.0 Fr/hr one gets from this personnel costs of 37.80 Fr/m^3. For the component performance considered, the personnel costs amount to about 75 percent of the total departmental costs. In order to obtain the latter, therefore, 20 percent equipment costs (i.e., 26.6 percent of the personnel costs = 10.05 Fr/m^3) and 5 percent material costs (i.e., 6.7 percent of the personnel costs = 2.55 Fr/m^3) must be added on. To the calculated direct department costs of 50.40 Fr/m^3 there are added, on the basis of empirical values 3 percent for the personnel staffing and 7 percent for the general building site equipment -- in other words, a total of 10 percent of the department costs. The unit costs for the foundation excavation thus amounts to 55.45 Fr/m^3 (earth excavation and rock excavation).

b. Assembly installations system A, B, and C

Similarly to the auditing process described under a, in the following table there are collected the cost functions employed for the calculation of the unit costs for these component operations:

Table for Calculating the Assembly Unit Costs From Cost Functions

Installation System	A	B	C
Work coefficient (AK) assembly	1.90	5.60	2.30
AK hand transport (mean distance 70 m)	1.90	2.20	1.10
Total AK (hr/m')	3.00	7.80	3.40
Rate (Fr/hr)	10.00	10.20	10.10
Personnel Costs (Fr)	30.00	79.60	34.35

Personnel costs in percent of the department costs (according to experience obtained in the investigations)	96.00%	89.00%	98.00%
Equipment costs corresponding to the preceding	4.00%	11.00%	2.00%
Department costs 100%=	31.25	89.45	35.15
Additional charges in accordance with the investigation results			
Personnel quota in percent of the department costs	3.00%	3.00%	3.00%
General building site equipment in percent of department costs	10.00%	10.00%	10.00%
Cable transport (main funicular 280 m, auxiliary funicular 150 m)	25.00%	10.00%	24.00%
Total additional charges in percent of the department costs	38.00%	23.00%	37.00%
In Fr/m'	11.90	20.60	13.00
Unit costs for assembly in Fr/m'	43.15	110.05	48.15

If, in analogy to the two examples, the unit costs are derived for all cost departments, then building upon this and adding the direct costs one can calculate the cost carrier unit costs. Needless to say, the values obtained by means of drastically simplifying assumptions only produce assertions about the order of magnitude of the unit costs to be expected and the minimal cost auditing merely constitutes an accessible route for the preliminary cost accounting. Even if the work coefficients can be rather accurately estimated by the construction administrators, still the assumptions with regard to factor prices, which are based upon average administrative salary rates, contain errors. They will deviate from the prices set by the entrepreneurs, depending upon the situation on the construction market, the composition of the labor force and various operational quantities.

Despite these reservations, the guide values derived by means of minimal cost accounting will be sufficient to allow the construction administrators to solve the problems of cost surveillance. At least it limits the uncertainty in judging the bids of entrepreneurs.

If gaps appear in the empirical values during calculation of the unit costs, then these gaps must also be filled by means of estimates, at the same time taking special conditions into account. To the extent that the same system of subdivisions from the BAS is employed for cost accounting the different construction operations, the missing data can be found by detailed investigations in suitable projects, combined with interoperational comparisons.

This also brings out the possibility of continuously checking all values relevant to the cost functions and the possibility of completing them and thereby taking into account technical development, in the course of carrying out construction operations.

7. Methods for Improving Efficiency

7.1 Work Studies

Cost statistics and cost analyses, supplemented by additional time measurements, produce important information with regard to possible methods of improving efficiency. Empirical results are obtained which suggest the areas in which improvements are to be sought. In addition, it is possible to estimate the effect of efforts to improve efficiency upon a general reduction of cost and from this to infer degrees of urgency for the measures to be taken. Since the problems in individual operations are quite different from one another, the emphasis will be placed upon explaining the methods of investigation. It must be left to the practitioner to determine, in analogy to the examples described, the best sequencing of work processes of another type.

7.2 Transportation Study

The principles governing work sequencing and time studies may be followed by some remarks regarding the informational value of work studies bearing upon considerations of economy and of procedure comparisons based upon a transportation study. The transportation of elements, building materials, and auxiliary building materials can be subdivided into transportation up to the project area and transportation within the building site. The building sites are divided into zones for the transportation studies. The problem is to find the most favorable combination of the various means of transportation for delivery to the building site and transportation within the building site within these transportation zones when the zones have been formed on the basis of building program delimitations, terrain configuration, and the computed cost rates. With the aid of computation formulas developed for this purpose, cost comparisons of various variants are carried out. Thus for example, the results can indicate those points up to which access by means of roads becomes optimal.

7.3 Machine Use

In searching for substitutable production devices (compare Burkhardt [3]) for the purpose of improving the efficiency of the construction operations by the use of machines, one must primarily give consideration to the production locations which are work intensive and which give rise to high costs. Among these must be counted the excavation of terraces, excavation of foundations, concrete pouring, and assembly work, since in these cost departments altogether 47 to 56 percent of the total cost is contained. This cost consists predominantly of personnel costs.

In connection with efforts to replace concrete foundations with ready-made foundations (where it must be borne in mind that for the prefabricated anchoring elements larger foundation holes must be excavated) there arises, first of all, the necessity of using a construction excavator [dredger]. An excavator, in accordance with the general requirements set for all construction devices, must be universally usable and hence capable of loosening and displacing rock and stone material just as easily as gravel or sand. Simultaneously, however, it should also allow a more efficient introduction of fresh concrete and of the building elements. In addition to these principles, the excavator must satisfy additional requirements which result from the special conditions surrounding avalanche construction building sites. Here we refer to the conditions which require moving up on narrow project access roads, which require mobility over the terrain and good stability on steep slopes. During the 1968 investigations, it was possible in two avalanche projects to employ an excavator which, with few exceptions, met the mentioned requirements.

The employment of an excavator results in a clear organizational structure in the work performance in addition to the proven cost savings. This makes it possible to employ the workers in accord with their capabilities and to shape the sequence of operations according to a logical plan. The advantages associated with this lead to further cost savings which, however, cannot be separately evaluated. The success of excavator use in two building sites, which previously had exhibited difficult building conditions, permits us to assert finally that there exist possibilities for improving efficiency by increased use of machines also in other projects which do not include especially rocky building ground.

8. Project Organization

In the book Project Organization With Network Planning Technique in Building Above Ground and Below Ground, Brandenberger and Ruosch [2] assert that in the field of construction in recent years great efforts have been made to improve the efficiency of engineering operations and to create aids for a comprehensive project organization. The authors see possibilities of obtaining further improvements in a project organization system with the aid of network planning technique. Here the principal task is to create an integrated system, building upon this technique, by the use of already existing subsystems (accounting methods with certain coded account numbers, survey programs, and accounting programs for the creation of submitted bid documentation and comparison of offers, et al.).

Also in avalanche construction projects the cost of planning and surveillance have increased markedly in significance. The ever more complicated processes of an economic and technical nature which must be exactly understood in a reliably conducted operation demand a suitable planning method. This method must meet the demands for a greater flexibility and an increased informational value in planning without at the same time overburdening the surveillance apparatus. This presupposes among other measures, the possibility of employing electronic computers in the evaluation. Moreover, attention should be given to the fact that to an ever greater degree a faster performance of the project is demanded and the public purse requires better and more abundant information regarding project performance.

Although planning has been done prior to this and projects have been satisfactorily prepared and carried out, for the reasons mentioned the efforts are usually still too small and they are certainly too little coordinated. In order to show how disadvantages or deficiencies often exist which prevent the attainment of a better system of project organization, some essential points will be briefly outlined in the following paragraphs:

Attention has already been drawn to the difficulties and deficiencies in cost accounting according to procedures practiced up to the present. Detailed cost analyses on the one hand bring out the necessity for increased planning and, on the other hand, create the foundations of a minimal cost accounting, realizable in practice without great expense, which can be built into a project organization system.

The phase before the beginning of construction is frequently too unrigorously formulated, planned, and adapted to project performance. To the extent that bar diagrams have been set up at all for the organization of the actual construction process, they are too coarse and do not show with sufficient clarity important functional relationships determining the course of the project. If the traditional planning devices are applied in more detail, this is associated with great expense so that adaptations to reality are wanting and many unfollowed-up planning operations lose their informational value. Disturbances of the course of operations, among which weather conditions are of special importance, have the consequence that it is often necessary to improvise boldly. In this connection, it should be noted that on the building site a construction supervisor or construction foreman who is a good improvisator is always of great value, since no planning or organization at reasonable expense can give information about small-scale changes. Still, even this organizational domain of daily activity is becoming more and more limited with the increased use of prefabricated elements.

Finally, in planning increased attention should be paid to the full utilization of the capacity of work forces and production facilities; this exerts substantial influence upon the size of the building program and the fixed costs.

The use of network planning technique offers one possibility for improving an existing planning system which has been criticized because of various deficiencies. The theoretical principles of this method have been explained, inter alia, in the "Buendnerwald" [6]. Their merits manifest themselves in the structure of a comprehensive project organization system which yields the principles governing time-referred studies of cost accounting and cost control and also governing capacity planning and the planning of work sequencing.

In the various domains of this planning method there are also contained many possibilities which are not fully exploited today. By means of planning which is thought of as a first step leading to the project organization system mentioned at the outset, in avalanche projects the following may be asserted by way of summary:

In network planning technique we have a method of planning which is suitable for the organization of avalanche projects and which substantially takes account of conditions produced by weather influences, complicated transportation systems, conditions surrounding engineering operations (falling rock, long approach routes, and transportation routes), limited storage and space facilities. At the same time it becomes possible to cope with the limited short construction time available by means of investigations which lead to an optimum utilization of workers and machines. The listed special conditions affecting avalanche projects hitherto resulted in uncertainties which led to hesitancy on the part of entrepreneurs when considering such an enterprise. By using the network plan, these problems are substantially solved and the construction operations are presented in the correct light, namely as familiar building operations being carried out under difficult conditions. Moreover, net planning technique also allows the construction supervisors to plan the manifold and often tedious project preliminary operations (land acquisition, forest-pasture designation, access, etc.) more purposefully and rigorously; also, it permits them, thanks to computer techniques of evaluation, to better prepare and supervise project performance, despite limited auxiliary personnel. Compelled by larger complex projects, in future many boards of works and their executing agencies will be obliged to employ an integrated system for project organization. When the broadest circles of contract consignors and contractors give thought to such possible overall conceptions, then it will be possible to develop an overall system which is satisfactory to the greatest number.

9. Summary

The technical problems of avalanche control construction have been substantially solved in recent decades. On the other hand, the treatment of managerial questions has lagged far behind the development of the structures. In consequence the entrepreneurs, building superintendents, and boards of works frequently lack documentation for cost accounting, cost surveillance, construction planning and financial planning in avalanche control projects.

Therefore, an investigation has been carried out having for its goal the clarification, based upon cost analysis, of the problems of the most favorable subdivision into cost departments for producing a practically useful cost accounting system. Out of the resulting insights, the procedures and aids for a comprehensive project organization have been developed. For this purpose, it was necessary to create, prior to the operations accounting and cost accounting, a construction operations key which was also regulated by the requirements of planning and organization, and which thereby represents a continuously constant structuring system.

The cost types are distributed into cost departments in the operations accounting sheets developed for avalanche construction operations. They are formulated in categories delimited in conformity with the operations in accordance with accounting theoretic points of view so that unit prices can be costed both for operations of the same type and also for the actual cost carriers.

The results of cost statistics indicate that avalanche construction operations are very work intensive. The cost share indirectly charged to the cost departments amounts on the average to two-thirds of the cost sum and it is composed of the costs assigned to the auxiliary cost departments and the main cost departments in equal amounts. The cost carrier unit costs are composed, during the construction program investigated, in part of various fractions of the indirect costs charged to the cost departments. The conditions responsible for these costs are investigated by an analysis of the individual cost department unit costs.

In order to be able to draw inferences, from the calculated cost, regarding the cost of construction, additional effects must be taken into account such as the character of the building market, parameters of production costs, etc. The effect of the resulting uncertainty factors, because of the decisive importance of the personnel cost component, plays a subordinate role in comparison to that of work-referred productivity. In order to obtain documentation for interoperational comparisons and data about the effect of the most important operational conditions upon cost structuring, additional work time derivations were carried out. The results, together with the values derived from the cost statistics, are compared as work coefficients for the various subperformances. This makes it possible to bring attention to functional dependencies upon various characteristics of the construction and from these to infer the order of magnitude of the corresponding ratios. In the sense of a minimal cost accounting, there is constructed, on the basis of cost functions, an accounting system which can operate in practice without great expense. In this way, there is given the connection between the construction work key, the operations accounting sheets, the results of the collection of cost statistics and time measurements together with their use in setting up cost functions and also in this way there are created the principles for a project organization system. The cost statistics and analyses, supplemented by additional time measurements, yield important information with regard to attempts at improving efficiency and the realization of these attempts is accomplished by means of work studies presented in the form of examples. The success of mechanization in producing improved efficiency in the cost-reducing sense is evaluated by taking as an example the use of an excavator for excavation and assembly operations.

From the results of the cost statistics collection and the work-referred productivity investigations, the great significance of planning can be inferred. Thanks to its comprehensive character, network planning technique in the building trade has in general proven itself in the solution of problems arising in this connection. Hence, on the basis of a building program, an investigation has been carried out of the suitability of this method for the planning and surveillance of avalanche projects. Experience in the project management of a construction program by means of network planning technique has shown that the procedure is excellently suited to the solution of most managerial problems in avalanche control construction. By using it as a basis and by using the described subsystems, it is possible to create an integrated project organization system which leads to the goals established at the outset.

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English Translation of German Titles

[1] Dictionary of Management

[2] Project Organization With Network Planning Technique in Building Above and Below Ground.

[3] Cost Problems of Construction Production.

[4] Correct Cost Accounting.

[5] Managerial Investigations in Structural Control of Avalanches.

[6] Network Planning Technique, Its Application in Forestry.

[7] General Theory of Construction Management.

XIV. THE SWISS FEDERAL GOVERNMENT'S SUBSIDIZING PROCEDURE (Walter Bauer, Bern)

Clearing and overcutting of forests together with forest grazing and generally poor management have in the course of centuries led to a sharp reduction in forest area, to a dropping of the tree line in the mountain regions, and to a thinning of forests. As a consequence, there have come inundations, mud slides, landslides, and not least of all, numerous avalanches. At ever shorter intervals the forests were devastated, individual farms, barns, and entire communities were endangered and transportation routes interrupted. The mountain population had little prospect of any effective material assistance. The communities and the educated classes were poor. Each individual was more or less forced to rely on himself and the assistance of his immediate neighbors.

With the Federal Constitution of 1848, there emerged for the first time a possibility of doing something in a common effort, i.e., on the federal plane, for the mountain population. But the time was not yet right for this, there was not yet any confidence in the disinterested altruism of the central power. Further natural catastrophes were required to awaken an understanding of the inescapable necessity for intervention on the part of the central government.

1. The First Federal Forest Law of 1876

In the year 1874, the Federal Government through Article 24 of the Revised Federal Constitution obtained the right to supervise the forest police in the high mountain areas. Then on 10 August 1876, there went into effect the first federal forest law as outlined by Prof. E. Landolt. Amongst other things it was intended to segregate protective forests from damaging influences of all sorts and in particular against avalanches. The law provided federal contributions for new forest parks and afforestations in protective forests to the extent that these were of great significance as protection against terrain dangers or to the extent that they were related to control constructions or to the extent that great difficulties were involved in the creation of such forest preserves.

The contributions were set at 30-70 percent of the cost of new forest parks, and 20-50 percent for afforestations in protected forests. We find here already a realization of the idea which was made clearer in later legislation that in particular existing thinned-out protective forests should be reestablished in order for them to be able to accomplish their purpose. The legislator was conscious of the fact that the mountain regions urgently required the helping hand of the Federal Government. Although at this time the Federal Government was low in resources, nevertheless, it had access to financial sources not available to the financially weak mountain cantons. Nevertheless, the magnitude of the contributions is surprising. The focus of the measures to be adopted was quite clearly in afforestations. The formulation of the text in the law and in the implementation ordinance leaves no doubt about this. The first installations supported by the Federal Government were purely afforestation projects.

A certain warm-up time was required before use was made of the contributing capabilities of the Federal Government. This may be related to the fact that the Federal Government also expected an appropriate contribution from the cantons -- an expectation which in the course of the years became a fixed principle.

During the first 20 years of the forest legislation of the Federal Government, the federal contributions paid out in the federal protective forest region of that time amounted to:

1875	Fr 12,000	(promised before the law went into effect)
1876	Fr 6,000	
1880	Fr 9,000	
1884	Fr 47,000	
1888	Fr 35,000	
1892	Fr 102,000	
1896	Fr 137,000	
1900	Fr 168,000	

These contributions include the total of funds paid out for afforestations and construction projects of every variety. By looking at the project records, one can ascertain that, for that time, the contributions were promised with a certain degree of lavishness.

The basic principle was: no avalanche construction without afforestation! This requirement encountered and continues to encounter today little enthusiasm on the part of the mountain population. The people are not very happy about reducing their pasturelands. The first avalanche structural control operations were still of a modest size: with the aid of ditches and posts, later on with earth terraces and free-standing walls, which subsequently were back-filled, it was thought possible to hinder the sliding of snow in the starting zone. The catastrophic winter of 1887/88 showed that these measures had only little success.

2. The Revised Federal Forest Law (EFPG) of 1902

The federal law regarding forest police of 11 October 1902, brought substantial improvements to the rates of contribution. These were increased by up to 80 percent for afforestations and control projects, and at the same time created the possibility of paying a lump-sum compensation to the amount of three to five times the yearly earnings for areas withdrawn from the economy for construction and afforestation. On the occasion of the partial revision of the forest law of 14 March 1929, this so-called earning-loss compensation was increased to 10 times the annual earnings. As was shown in the sequel, this was both materially and psychologically an extremely valuable extension of the contribution possibilities. Much doubt and resistance on the part of land proprietors with regard to the necessity of afforestations and control constructions can be eliminated and valuable time gained by such measures. The revised law also brought with it for the first time a contribution for forest roads, and this was of special use in making the usually remote afforestation areas and building sites accessible.

The new forest law allowed a substantial intensification of the battle against the "white peril." Year after year, operations were carried out in the starting zones of avalanches. It is an astonishing fact that thanks to the abundant contributions made by the Federal Government it was possible even during both world wars for substantial operations to be carried out in afforestations and structural controls.

It was the goal of the contribution policy to prevent as much as possible interruptions in the operations.

At times there were some disadvantageous consequences of periods when the Federal Government was in a bad situation financially. There were a whole series of financing programs intended to apply the scanty financial resources where they were most needed. Thus, in the thirties, it was necessary at first to reduce the contributions by 25 percent and later even by 40 percent. In addition to these reduced funds, in the course of the years, credits were also substantially reduced. The cantons were on their part compelled to make similar decisions. Since 1934, the credits for afforestations and control constructions were assigned to the financing of the works of the Federal Snow and Avalanche Commission.

In the years 1920, 1922, 1948, and 1961, the administrative and technical aspects of forestry projecting were summarized and clarified by the Department of Interior in so-called "specifications for the creation of forest projects."

3. The Avalanche Winter 1950/51 and Its Consequences

Thanks to the high contributions of the Federal Government, since 1876 it has been possible to reforest and structurally control numerous avalanche paths, slopes, peaks, and starting zones. There was a general belief that in this domain no surprises were to be expected -- not to speak of catastrophes. The enormous snow quantities of the winter 1950/51, the resulting numerous avalanches, the lamentable victims of the white death, and the immeasurable material loss proved in a painful manner that natural catastrophes can always reappear. In spontaneous generosity, the people and the officials combined to stand by the victims of the catastrophe. There could be no misunderstanding about the fact that the Federal Government was confronted by the urgent task, in addition to meeting the immediate emergency, of creating the required legal foundations which would for the future exclude such destruction to the extent that it was humanly possible. As early as 6 December 1951, the Federal Council was empowered by both chambers, in an amendment of Article 1, Section 1, of the Finance Ordinance of 1939-1941 in its extension to 31 December 1954, to guarantee federal contributions in undamaged areas, such as in particular for afforestations and structural controls.

In addition, the federal law of 1902 (EFPG) was supplemented by four new articles which provided an extraordinary aid for relief of the avalanche damage of the winter 1950/51, in addition to increased afforestations and control constructions. This supplementation was as follows:

Article 37bis [second part of Article 37] covered

a. the restoration of thinned-out protective forests;

b. the construction of avalanche-deflecting walls, splitting wedges, protective spaces, and similar installations not only for securing the protective forests but also for general protection;

c. the resettlement of avalanche-endangered buildings to safer locations, and also the creation of galleries for the protection of railroads, highways, and roads whenever thereby it was possible to avoid the expense of costly control structures in avalanche starting zones.

According to Article 42bis, the Federal Government can guarantee contributions up to 80 percent for the installations listed under a and b, including the necessary roads and fenced-off areas, while for the galleries listed under c, the government can contribute up to 50 percent and for the resettlement of avalanche-endangered buildings up to 30 percent.

Article 42ter [third part of Article 42] made the federal contributions dependent upon suitable outlays on the part of the cantons.

The guarantee of these contributions was over a period of 10 years for the galleries and resettlements and for all other installations over a period of 30 years.

Following this and thanks to the measures adopted by the Federal Government, afforestations, control constructions, and the creation of galleries have increased tremendously. On the other hand, practically no use was made of the possibility of resettling avalanche-endangered buildings. The reason for the absence of the resettlements may be found in the high costs and in the proportionately low contribution rate but also in the circumstance that it often turns out to be difficult to find suitable construction sites without -- to name one of the most frequent cases -- substantially impairing agricultural operations. It is generally preferred to protect endangered individual buildings by means of deflecting constructions, terracings, etc.

From 1875 to 1928, the federal contributions paid out for afforestations and constructions of all types remained substantially below 1 million francs. In the years 1929-1935, they were about 1 million francs, but in 1936-1948 they again dropped considerably, while in the years 1949-1951 they amounted to slightly above 1 million. After 1952, the contributed sums increased abruptly: to over 4 million francs in 1954, almost 9 million in 1958, and up to what has thus far been the maximum of over 14 million in the year 1967. Although a substantial part of these contributions is also assigned to afforestations outside the avalanche area, still the development is distinctly characterized by avalanche defense construction.

New avalanche descents of substantial size in the winter 1968/69 causing considerable losses in human life and material damage caused the federal councillors, in the federal law of 21 March 1969 on the amendment of the EFPG, to reassume the federal contributions (expired in 1962) for the construction of galleries and the resettlement of buildings, the subsidy being until 1 May 1982.

This report on the subsidizing policy of the Federal Government would be incomplete if nothing were said about the federal law governing investment credits for forest industry in the mountain region, dated 21 March 1969. This law provided a way of financing the residual costs for avalanche constructions and the associated afforestations in financially weak communities by guaranteeing a loan at no interest or low interest.

In conclusion and in summary, retrospect shows that since the beginning of its forest legislation the Federal Government has on a large scale supported avalanche control projects and the associated afforestations. These operations have in the course of decades been continuously improved and adapted to the special conditions prevailing in the mountains.

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XV. POLITICAL ASPECTS OF AVALANCHE PROTECTION

(Gaudenz Bavier, Chur)

Many people have probably already asked themselves why avalanche control construction has been assigned just to the forest service. The greatest part, at any rate, of the permanent structural control and avalanche protection measures in the track and in the starting zone is to be found outside the forest and has little or nothing to do with cultivation of woodland. The reason, nevertheless, why avalanche structural control is assigned to the forest service is primarily to be understood through the historical development. W. Bauer has described this history clearly in his preceding article, to the extent that it relates to legal regulations. The principle expressed in that article: "No avalanche structural control without afforestation," i.e., without restoration of the protective forest, shows clearly and unambiguously that only the forest engineer is in a position to meet these requirements. But there is still another reason. Through the legal regulation dividing the cantonal region into suitable forest districts and their further subdivision into forest regions, an organization was created which lies like a network over the entire country and by means of which a systematic coordinated avalanche observation activity can be guaranteed as the foundation of any protective measures. And finally, at the time when the federal forest law of 1876 went into effect, Chief Forest Inspector Johann Coaz, the patriarch and founder of systematic avalanche structural control, was at the head of the Swiss Forest Service. It was he who -- at that time still cantonal forest inspector in Graubuenden -- in 1868 caused district forester Rimathe to create what was presumably the first systematically designed avalanche construction project in Europe, the "Motta d'Alp" in Tschlin at a cost of 1,603.75 francs. The project embraced 412 m' of free-standing dry walls and 17 rows of posts totaling 509 m' in length. As early as the year 1881, at the instance of the Federal Department of Trade and Agriculture, he published his fundamental work on "The Avalanches of the Swiss Alps" containing the first cartographic data for avalanches in the Gotthard region, prepared by the then Federal Forest Assistant Fankhauser. In this work the author writes:

"What led me to the study of avalanches and their structural control was my former position in connection with the Swiss Atlas and my 30 years' service as a mountain forest ranger." The activity of the forest engineer in the mountains brings him continuously into contact with the natural phenomena related to avalanche descents and confronts him therefore with the problems of avalanche protection. Hence, he is predestined, both by his function and by his education, for avalanche structural control. Hence, it is not really remarkable that this great and responsible task lies in the hands of the forest service and that also the Federal Institute for Snow and Avalanche Research in Weissfluhjoch-Davos is associated with the Federal Forest Inspectorate.

Since the first federal forest law went into effect, a total of over 13 million francs has been expended out of forest credits for [avalanche] structural control projects and afforestations with the Federal Government providing subsidies up to about 196 million francs. The following Table 1 gives information regarding the details.

In contrast to the contributions to the provision of forest access, forest consolidation, segregation for forest pasturage, etc., these subsidies are not a compensation for legally restrictive regulations affecting forest property but are a direct aid to the mountain population. It is, therefore, reasonable that the subsidizers, Federal Government and cantons, attach certain conditions to the payment of these high contributions and reserve to themselves a right of consultation. Thus, the Federal Forest Inspectorate has caused binding guidelines for avalanche structural control in the starting zone to be worked up by the Snow and Avalanche Research Institute. These guidelines take into account research over many decades and also take into account practical experience and they are primarily concerned with the requirements imposed by nature upon a control project and upon the individual installations. Designers of avalanche construction projects which are to be subsidized must adhere strictly and without exception to these guidelines. The subsidizing authorities reserve to themselves additional consultation rights with regard to operations contracting and naturally with regard to the performance of the operations.

Table 1. Auditing of Afforestation and [Avalanche] Structural Control Projects (Avalanche Structural Control Galleries) From the Year 1876 to the End of 1970. According to Data of the Federal Forest Inspectorate on 4 January 1972

Cultivation		
Area in hectares	30,879	
Deciduous trees in thousands	91,255	
Evergreens in thousands	171,675	
Total [trees]	262,930	
Total cost		Fr 80,505,881
Drainage		
Total running meters	5,009,273	
Total cost		Fr 16,250,904
Avalanche Structural Control		
Running meters [total]	184,560	
Galleries (since 1953)	8,373	
Rock Fall Structures		
Running meters	31,739	
Earth Terraces		
Running meters	560,363	
Wall Terraces		
Running meters	417,823	
Total cost		Fr 135,486,277
Stream and Terrain Construction		
Stream running meters	332,023	
Soil stabilization running meters	1,027,731	
Total cost		Fr 15,048,036
Enclosures		
Running meters	2,632,369	
Total cost		Fr 10,571,880
Road Construction		
Patrol roads, running meters	2,098,555	
Jeep roads, running meters	758,387	
Total cost		Fr 49,241,724*
Fire Protection		
Total cost (since 1958)		Fr 1,369,832
Ground Acquisition		
Total cost		Fr 10,151,493
Aggregate cost		Fr 318,626,027
Total federal funds paid out (61.52 percent)		Fr 196,014,904

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* The actual forest-road construction is not included in this figure.

In the course of the approximately 100 years since we in Switzerland have been systematically producing structural control for avalanches, with these operations being subsidized by the Federal Government and the cantons, not only the nature of the construction but also the purpose of the construction as well as the nature of the object to be protected by the construction have materially changed. Before World War II, the mountain population still consisted predominantly of mountain farmers or of people closely connected with agriculture in one form or another and who were familiar with the mountain environment. The mountain farmer was primarily self-supporting. Through the winter, during the period of reduced agricultural activity, he occupied himself usually in the forest in gathering wood and transporting wood. He was familiar with the onerousness and danger of the snowy mountain winters. Winter sports continued to be confined to some relatively few health resorts and in summer, the main season, the sport centers of today are still predominantly true, tranquil spas. Mountain railways, ski lifts, and so on existed only in rather limited numbers. The mountains were in summer and in winter the almost untouched arena of mountain climbers and ski tourists.

This has changed fundamentally since then. There is now hardly a single even moderately attractive mountain in the alpine territory on which there is no railway or ski lift either existing or at least projected. Thus, today in Switzerland there are over 100 funiculars [aerial cable cars], about 70 chair cars, and nearly 700 ski lifts in operation which all serve to haul skiers of limited ability up into the mountains. This confronts the communities, the resort associations, and transportation associations and those companies operating these transport facilities with the inescapable duty to concern themselves with securing that the guests, frequently unfamiliar with the mountains, thus brought up into the highlands should be returned again to their starting point unimperiled and uninjured. But precisely the same responsible duty confronts the conductors of ski tours who, together with the people entrusted to them, visit the winter mountain world on the ski slopes. In this, avalanche protection has acquired a new and very important function hitherto unknown.

New winter sports centers have in recent years sprung up like mushrooms. In the Canton of Graubuenden alone there are about 40 winter sports centers of importance. The structure of the population has altered. The mountaineer population familiar with the mountain winter has been augmented by outsiders often completely unfamiliar with the mountains who look to the winter sports regions partly for recreation and partly hoping to make a living. With increasing motorization and the resulting expansion of the road system, the mountain regions are now easily accessible from the centers of population. Thousands upon thousands of skiers spend their vacations and weekends in the mountains. It is estimated that today there are in Switzerland about 1.5 million and in Europe about 15 million skiers and it is expected that by the year 1990 there will be a doubling of the tourist volume. In Graubuenden and in the Waadtlaender Alps today the number of winter visitors exceeds that in the summer.

The mountain farmer, originally an introvert and living in a more or less isolated and in part inaccessible region was carried along in this development. There opened up to him and particularly to the young people new employment possibilities which in certain regions were completely exploited "down to the bottom of the barrel." The land which had earlier been managed agriculturally acquired increased value as building land which unfortunately was in great measure acquired by speculators with the assistance of the native population. Large-scale overbuilding resulted and the existing health resorts turned into actual mountain towns with all their accompanying phenomena, some of them not exactly pleasant.

But it was not only the former winter health resorts which expanded but also small and even the very smallest mountain villages were attacked by the building boom. Thus, for example, a town planner familiar with conditions in Graubuenden found that in one small locality in upper Engadine in the year 1964, building sites were being sold for about 2 million francs. The spreading prosperity makes it possible for many people to build a vacation house in the mountains or to at least rent a vacation dwelling occasionally. Requests for building permits on the part of outsiders increased in the mountain communities and a frequently planless building-up of large areas formerly used by agriculture became widespread. It was unavoidable that thereby regions were claimed for development and are still being claimed which are potentially exposed to avalanches. The communities thus see themselves confronted by very difficult problems, for as the possessors of the local police authority they are responsible for order and safety within their territory. A part of this local authority consists of issuing building permits and inspecting new buildings. Thus, the communities are confronted with the question as to how they should proceed in the case of building permit requests in avalanche-exposed territory. There exist no federal regulations or laws of a binding character. The Federal Department of the Interior adopts a viewpoint which is doubtless in accord with our federalist structure, to the effect that the preparation of avalanche zoning plans is the affair of the mountain cantons, or of the communities concerned, since it is primarily a function of the communities to secure the safety of its inhabitants. But as early as 1952, the department pointed out the urgent necessity of working out avalanche zoning plans and avalanche cadastral surveys and declared unmistakably that the Federal Government would make no contributions to resettlements or to measures protecting buildings against avalanches if in the selection of the building sites no attention was paid to avalanche zoning plans or if, when such plans were absent, warnings against building projects were ignored.

It is to be hoped that by means of the legislation based upon Article 22$^{\text{quater}}$ [fourth part of Article 22] of the Federal Constitution, on regional planning, the cantons can finally be effectively obligated also on a basis of federal law to support the segregation of endangered zones.

To be sure, it is correct that enthusiasts for building who develop avalanche-endangered regions in irresponsible carelessness and in disregard of warnings must in the event of a catastrophe bear the consequences of their improvidence. But this in no way solves the problem for as a consequence of developing such regions other people are also endangered. These may be those who are engaged in any activity in this region, whether they are visitors, vacation guests, letter carriers, etc., or possibly even rescue crews.

Thus the communities, being responsible for the safety of their inhabitants, are compelled to prevent construction in avalanche-endangered regions. For this purpose they require the building inspector's instrumentality of a map of avalanche zones or of danger zones. Thus, the avalanche zoning plan becomes part of the community zoning plan. In contrast to other zones whose designation can be freely arranged by the communities, the danger zones have a fixed delimitation given by nature which cannot and should not be arbitrarily displaced. Of course, it is undoubtedly true that in delimiting danger zones there is involved a survey which is characterized by the technical competence and personal views of the expert consultant involved, who is usually the responsible district forester. As a rule not too much margin is allowed in this survey. The survey, to the extent that it relates to the red zone involving a high degree of danger and absolute building prohibition, takes the form of relatively small boundary shifts since this zone includes regions having rather uniformly increased avalanche activity for which as a rule there exist observations and often avalanche photographs and which usually also display in the terrain unfailing signs to the eyes of the attentive and skillful observer. Somewhat greater margin may be expected in surveying the boundaries of the blue zone, in other words, the zone of less severe risk, relative to the white zone which is the unendangered region. De Quervain has expressed himself with regard to the avalanche catastrophe of 1968 in Davos as follows relative to this problem: "If one wishes to exclude all possible risk by taking as a basis of zoning not only the regular avalanche activity but also all isolated historical events then various well known localities would have to place entire regions under the ban." And again he writes: "Thus probably in the future there will remain a residual risk, whether because in the space of centuries one must accept one enormous catastrophe or because more frequently one must reckon with less intense damage. The estimation of the magnitude of the risk for various parts of the terrain is the concern of persons familiar with the locality and if possible familiar with avalanches. But the assignment of responsibility must ultimately be done by a political authority."

The assignment of responsibility by the political authority, in other words as a rule the community assembly, is not likely in the case of the red zone to be substantially different from the professional opinion of the expert advisors since otherwise this assignment would be open to the reproach of arbitrariness. An avalanche zoning plan can lay claim to accuracy only when it has been constructed completely and on the basis of recommendations of expert agencies, in other words, principally of forestry agencies. Otherwise it at least contradicts the specifications in the area of building inspection. An avalanche zoning plan based upon factually ill-supported and incomplete data would therefore have to be denied the recognition of its legality and hence denied approval on the part of the cantonal government. In this connection, it should also be asserted that the building inspection procedures of dividing a piece of property into a zone where building is prohibited because of avalanche danger and a zone of restricted building in no case justifies claims for compensation on the part of the property owner. The Federal Court has brought this out with all clarity in a recently published decision.

But this in no sense brings us to an end of the problems of the avalanche zoning plan. The quite concrete question arises whether by means of avalanche control structures it is possible to bring about a rezoning from red to blue and possibly even to white. In our opinion, the safety guaranteed by avalanche structural control being only relative and not always the same, the possibility of a rezoning into white (i.e., nondangerous region) is in very many cases excluded. On the other hand, under certain assumptions and depending upon local conditions, it is possible to give consideration to a reduction of the red (severely endangered) zone. This can have the consequence that land which hitherto was usable only agriculturally becomes revalued as building land and thus multiplies its value severalfold. In such a case, it is probably only right and proper if the owner of the revalued land should be required to pay a share of his gains toward structural control in the form of a perimeter contribution. But such a rezoning should be carried out with the greatest care and only in well founded cases -- where financial interests cannot be looked upon as the reason.

The avalanche zone plan has an incisive effect also upon insurance against natural hazards. Natural hazard policies as a rule refuse to insure structures in the red zone and in the blue zone require certain protective measures which have the effect of increasing building costs. The insurance compensation rates to relocate a building destroyed by an avalanche should be the same as construction costs at the former site. When possible, the relocation should even be demanded. It is therefore highly questionable when in an appeals case a request is made for rebuilding on the old site with the justification that with normal snowfall there is no avalanche danger. Likewise questionable -- in another case -- is the argument that the construction of a house in an avalanche-endangered region still constitutes no immediate danger to public order and safety and therefore building inspection measures are not justified. Neither can a normal snowfall be cited in judging avalanche risk nor is the immediacy of the danger of decisive significance; because avalanche danger can only be dealt with in a preventative way and it is precisely with this purpose that avalanche zoning plans are created.

We have shown in the preceding that the avalanche zoning plan is a part of the community zoning plan, in other words, must be a constituent of the regional planning. But this applies not only to zone segregation but also to avalanche protection in general. Avalanche construction in all its aspects must also be included in planning. In particular, before the erection of avalanche control structures, there must be a clarification of the social, economic, and political development of the settled area which is to be protected. On the basis of careful data collection, favorable regions should be designated for which the high cost of avalanche control projects is acceptable. This is not to be interpreted as meaning that an almost exclusively agricultural valley should simply be left to its fate and that no protective measures should be applied there. To the extent that such a region requires an expensive avalanche protection, a careful and unprejudiced check must be carried out of the development of this region to see whether sufficient possibilities exist to guarantee the population an adequate base for existence over a foreseeable period of time or whether the development possibilities are so slight that one must reckon sooner or later with depopulation. At the same time, there should also be a thorough examination of the question whether maintenance and protection of the settlements might not possibly be necessary for purely landscape-esthetic reasons. In each case it should also be determined whether resettlements might not be more advisable and in particular safer than expensive control projects. The latter course, as Bauer has already shown, is not generally very popular, first of all because of the difficulty of finding suitable building land, and then because of the difficulties which this entails in the agricultural allotment of property and not least of all also because only relatively low subsidies are obtainable for a resettlement. It is precisely in the financially very costly process of avalanche control projects, which is sustained practically entirely by public funds, that planning measures are necessary even though the latter are a ticklish subject which readily excites the emotions. It is doubtless also necessary to periodically recheck the suitability and economy of these public investments, to the extent that one may speak of economy at all. This view may seem harsh, but to us it appears indispensable that all these aspects should be thoroughly thought out if it is to be possible to obtain the existing resources and use them correctly. There is a final aspect which must not go unmentioned here. On the occasion of the avalanche catastrophes of 1951 as well as 1968, a collection was taken up in Switzerland for those hurt by the avalanches. The results of the collection were extraordinarily gratifying and impressive, being over 14 million francs in 1951 and in 1968 over 5 million francs. In this way, many victims could be quite significantly assisted at least financially. But the fact merits thinking about here that the major part of the uncovered damage consisted of insurable objects, i.e., that the collected money had to be spent for the most part for material damage in cantons in which there was no obligatory insurance, and that in cantons with obligatory insurance a large number of the buildings were underinsured. This creates inequalities in the treatment of the victims and thus leads to disagreements. In our opinion, an attempt should be made to determine whether or not as a condition to be attached to future subsidies of avalanche structural control projects, it should not be required that buildings and goods and chattel in the settled area to be protected be insured whenever possible at the undepreciated value or whether in some way or other obligatory insurance could not be introduced into such regions. It will hardly do in the case of an avalanche catastrophe to put off the owner of an uninsured or underinsured building with the advice that he should simply have insured sooner. This would be in opposition to the spirit of the public donation and besides, in such a case, the need is too great for such subterfuges to be employed. But the discontent remains and it would be a welcome event if upon those regions, too, there began to dawn the meaning of the proverb: "He who saves in time has means at need."

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English Translation of German Titles

[1] The Avalanches of the Swiss Alps.

[2] Guidelines Concerning Afforestation and Structural Control Projects in Avalanche-Endangered Regions.

[3] Legal Questions Establishing Avalanche Zones in Which Building is Prohibited.

[4] The Avalanche Zone Plan.

[5] Appeals Practice for the Small and Large Councils in the Canton of Graubuenden.

[6] Snow Science and Avalanche Control Structures.

[7] The Avalanche Catastrophe of Davos: Observations and Conclusions.

XVI. THE FOREST AS A PROTECTION AGAINST AVALANCHES (Conradin Ragaz, Tamins)

1. Importance of the Upper Tree Zone

Technical avalanche construction is not an end in itself but a means of averting dangers which arise in all places where, as a consequence of human carelessness or greed, dwellings or other facilities have been erected in regions which since the earliest times have been threatened -- but not at regular intervals -- by avalanches, which in most cases break loose far above the tree line. Great, too, are the expenditures of communities, cantons, and the Federal Government to guarantee endangered villages and transportation routes necessary security against these natural forces. In Graubuenden Canton, the majority of these projects are in progress or have already been completed. Thanks to Article 48 of the cantonal forest law of 6 October 1963 and with the aid of the danger zoning based upon that law, a restriction has finally been put in the way of further building in the endangered regions. Technical avalanche construction will, to an increasing degree in the future, be concerned with reestablishment of mountain forests which are no longer capable of fulfilling their important protective function because man has not accorded to them adequate care and nurture or because natural forces of all types such as avalanches, fire, or storm, have damaged the upper forest zone. Technical avalanche construction becomes an aid for maintaining in optimal condition the forest border zones which constitute biological avalanche protection.

If we weigh, on one hand, protective forests granted us by nature and, on the other hand, artificial avalanche construction, then we obtain the following comparative values:

a. with regard to extent:

1) avalanche construction projects and afforestation projects which are now in progress in Graubuenden Canton embrace an area of about 2,500 hectares or 1.5 percent of the total forest area.

2) the total length of the upper forest border, which lies at various altitudes and is frequently interrupted by avalanche paths, rock falls, or slides, amounts to about 1,400 km. Of decisive importance for biological avalanche protection is not the upper tree line but the upper tree zone which may be assigned an average width of 200 m. Hence it amounts to about 28,000 hectares or 16.37 percent of the total forest area of 171,000 hectares in Graubuenden.

b. with regard to cost:

1) for permanent avalanche construction, 500,000 to 600,000 francs per hectare are to be spent, out of which theoretically there arise annual interest burdens of 25,000 to 30,000 francs.

2) the protective forest is normally capable of maintaining itself substantially in the upper tree zone and with suitable access and cultivation, depending upon the tree varieties, it can even produce a modest net yield.

This comparison, which has been kept concise in view of the limited space at our disposal, gives us an insight into the extent of the upper tree zone and permits us to recognize the dominant significance of the forest for avalanche protection. The purpose of the following discussion will be to describe in more detail the unique biological community -- the forest -- from the point of view of its function as a protection against avalanches -- although it, at the same time, has many other functions.

Within the context of the total concept, it is a question of placing the proper accents in the sense that technical avalanche construction for the protection of existing settlements and transportation routes represents an urgent task for our generation, while, on the other hand, the maintenance and nurture of the forests of the upper tree zone must be looked upon as a lasting responsibility.

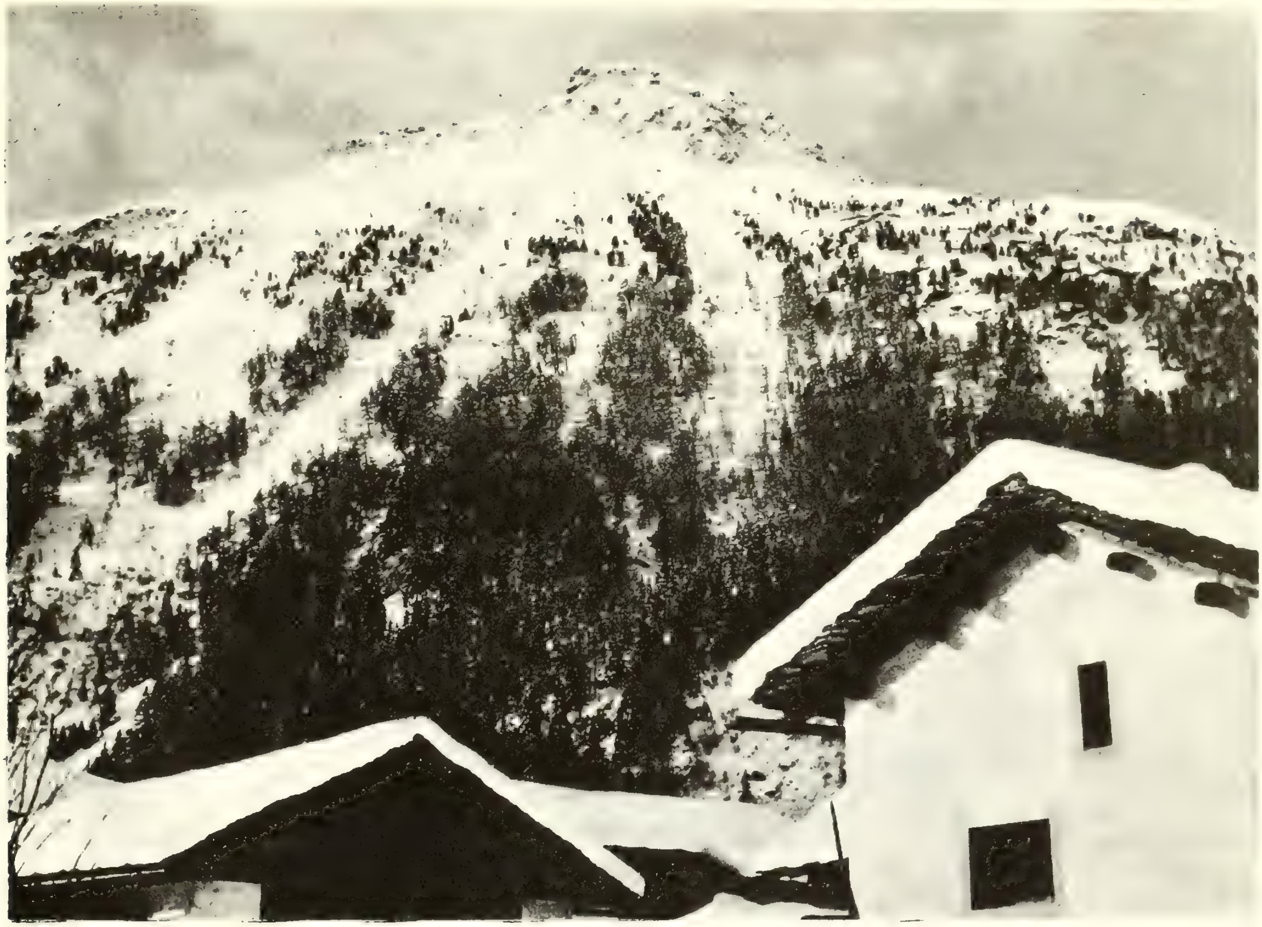


Figure 1. Protective forest penetrated by several avalanche paths; in such cases, artificial control structures are required in the starting zones in order to completely close the forest belt once again (photo C. Ragaz).

2. Ecology, Tree Varieties, Structure of the Forest Stand

The mountain forests, which are of particular importance for avalanche protection, lie in the boundary zone between subalpine and alpine elevation levels. On the northern slope of the canton they are at an elevation of 1,700 to 1,900 m above sea level. In the central alpine region, they are between 1,950 and 2,150 m above sea level. The following discussion is limited exclusively to this upper tree zone.

Every variety of tree is associated with quite a definite stand location which it finds suitable. Prevailing climatic and soil conditions are of primary significance. The steepness of the terrain, the disadvantageous effects of the snow cover, and erosion are also of great importance. In the region of the upper tree line, only plants and trees which possess quite special characteristics can survive the extremely difficult environmental conditions and thrive. The winter, which lasts up to 8 months, interrupts the growth of the trees during a period of maximum temperature variation and strongest mechanical stress. During the short vegetation period, there are dry periods to be overcome and the number of days which display a daily temperature average above 10°C is close to that lower limit which begins to be critical for the tree's growth. Therefore it is understandable if out of the 500 evergreen varieties existing on earth, only a few varieties are capable of penetrating to this elevation which is so extremely inimical to vegetation. Besides the larches, which discard their needles in the winter, there are mountain fir, spruce, and Cembran pine. The only representatives of the approximately 9,500 deciduous varieties are the birches, willows, mountain ash, trembling poplar and alpine alder which, with the exception of the latter, do not form a stand and are of subordinate significance for avalanche protection. Attempts to augment the tree varieties of the subalpine highland by means of evergreens from the boreal evergreen forest zone (Siberian larch, Siberian pine, and Siberian Cembran pine) which would appear to be promising considering the common features displayed by the boreal and alpine evergreen forests have thus far not let to success. The four tall evergreens which are capable of tolerating the extreme stand locations to the very end occur simultaneously as stand-forming trees only in certain locations. In broad regions, it is only spruce or the mountain fir alone or at most with a mixture of larch which participates in the buildup of the pioneer forest of the high mountain regions. On the other hand, the larch-Cembran pine climax forest in the central massif is frequently encountered where it represents the most well-adapted forest community of the highlands. The mountain forester must know how to get along with these limiting natural conditions with regard to tree varieties.

The structure of the forest stands which survive in the upper tree zone is highly variable depending upon the varieties of trees present. The mountain fir stands of the lower Engadine are characterized by the greatest uniformity and by dense stand closure.

The evergreen belt of the subalpine spruce forests is always of uniform structure whenever it has come from areas under attack by the forces of nature, from former grazing regions, or from clearings. Often the effect of human beings, because of the utilization of scattered stands over many decades (selection) has led to a stand having a stepped structure.

The larch-Cembran pine forest is very often two-layered, with the older larch forming the upper layer and the Cembran pine forming the young forest. It is evident that here the vegetation development must finally lead to the pure Cembran pine forest.

Pure, over mature, and partially broken up larch forests which have been grazed, may be encountered in places on southern exposures. As a result of intensive grazing, they are forests completely without regeneration and are no longer able to provide their protective function permanently.

The volume of the forest stands on the upper tree zone averages 200 to 250 cubic meters per hectare. The annual increment in the central Alps is 1 cubic meter per hectare and may increase on the north slope to 1-2 cubic meters per hectare.

3. The Effect of Forest Stocking on the Mechanical Behavior of the Snow Cover and Upon Avalanche Formation

Among the causes of avalanche and snow slide formation are:

a. Long sustained snowfalls,

b. unfavorable snow cover structure (layering),

c. wind transport and drift formation,

d. sudden heat waves,

e. terrain-induced tension fields.

Between tree vegetation and the snow cover, there exists a close mutual influence which is of decisive significance both for the growth of the forest and also for avalanche formation.

An ideally constructed, i.e., a healthy forest with the permanency appropriate to its age-class is capable of hindering avalanche formation upon the emergence of the above-mentioned conditions. The unevenness of the crown leads to a nonuniformity and densification of the snow cover because a part of the snowfall at first remains hanging in the crowns and often gets to the ground only after the next period of warmth. The stand space, with its boughs, branches, and needles, has a favorable effect upon the snow deposit under a strong wind, and in this way is capable of preventing undesirable accumulations of snow in otherwise unstable slope positions. A forest with a stocking of 1,000 to 5,000 individual trees per hectare can nail the snow cover fast to the ground and thereby prevent the outbreak of avalanches on the steep slope or in the tension field.

On the other hand, the snow is an extraordinary burden upon the growth of plants. Thus, the settling of the snow cover leads to mechanical damage in young plants. On the steep slope, the gliding and creep of the snow cover and the resulting snow pressure lead to bole deformations and often to the complete destruction of new plantings or young plants. Avalanches or snow slides starting above the tree line can even lead to the partial destruction of intact forests and display a tendency to penetrate ever further into the forest stands in the course of the years until finally there arises an open avalanche path. It is important to deal promptly with such a serious development, and this is possible by control structures in the starting zone, which are often not very extensive.

A long-lasting snow cover, particularly on slopes with a northern exposure, can lead

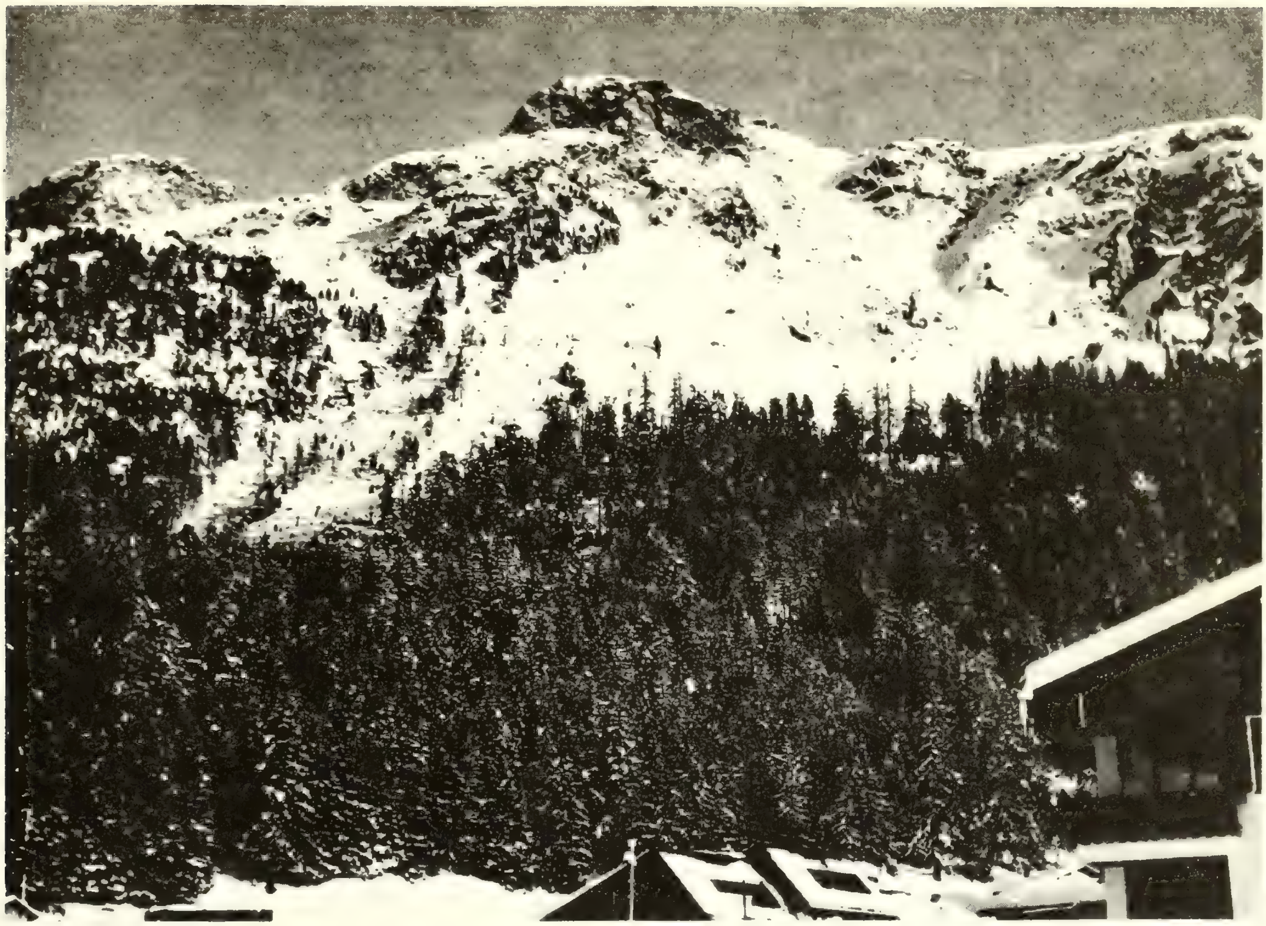


Figure 2. This favorably developed mixed high-elevation forest forms a reliable protection against avalanches (photo C. Ragaz).

to an infestation of snow mold fungus and to a shortening of the vegetation period. The snow cover forms a protection for the young plants with regard to the effects of wind, drifting snow, and grazing wildlife.

From these conditions and observations and taking into account the circumstance that the mountain forest on the upper tree line performs a number of other functions in addition, there arises the following goal:

a. Conservation and restoration of the forests of the upper tree zone, in order that they shall be able to completely fulfill their important protective functions.

b. As broad a reforestation as possible of the deforested alpine level up to the natural tree line with the purpose of strengthening the pioneer forest.

The following long-term measures appear to be suited to the realization of this goal.

4. Measures

Prerequisites for improvements in the area of the upper tree line are control of grazing, of the density of the wildlife population, provision of access, and finally, structural control to prevent snow slides and avalanches within or above the tree line. Here we are concerned with a detailed account of the forest structural measures which appear suited to an improvement of avalanche protection.

It has been asserted that every tree variety displays advantages and disadvantages with respect to avalanche protection. Therefore, a mixture of tree varieties promises to produce the best results and one should avail oneself of every possible extension of the tree variety spectrum, even employing deciduous trees.

The stand density which is necessary for an effective avalanche protection in the neighborhood of the ground, i.e., in the region of the snow deposit, can be best obtained by an ample restocking over the whole area of the stand. Hence, the greatest significance should be accorded to suitable restocking measures and increased cultivation. These restockings should be kept densely closed up to a height of 3-4 m. Subsequently, suitable measures are necessary for the formation of well-crowned, resistant individual trees.

The effect of the forest upon the snow cover conformation is very dependent upon stand height. The greater this is and the more extensive the forest stands are, the more permanent will be the effect upon the action of the wind. Therefore, it is unconditionally necessary to strive for permanent conservation of an upper layer consisting of fully grown trees. Any clearing of old trees, which would lead to decades or reduction in stand height and its effect upon the wind, is to be avoided.

In the search for that stand structure which best meets the requirements of avalanche protection, the following alternatives may be considered. Theoretically and during a limited period of time, a densely closed, single stratum stand substantially satisfies the requirements imposed from the point of view of avalanche protection. Thanks to the large number of stems per hectare and an almost completely closed crown canopy, this type of stand can substantially prevent the penetration of snow into the interior of the stand and hence can make avalanche formation impossible. But the single-stratum type of stand is not permanent so that inevitably the time approaches when felling must lead to a temporary reduction in the stand height and in the avalanche-protective effect. Forest stands with an uneven canopy are capable of taking up new snowfalls with small risk of damage and of later depositing the snow on the ground, display great advantages in the upper tree line. The stand has well-branched trees of all ages interspersed in it and is therefore very effective against the wind. Ample incident light through clearings permits the dissemination and growth of natural restocking. In the subalpine spruce forest, the selectively cut forest is the most suitable type of operation for meeting the requirements which have been set.

In the range of the larch-Cembran pine forest, one should strive for a restocking of the larch under an umbrella of old trees. The Cembran pine is suited to the desired increase in the density of the stand.

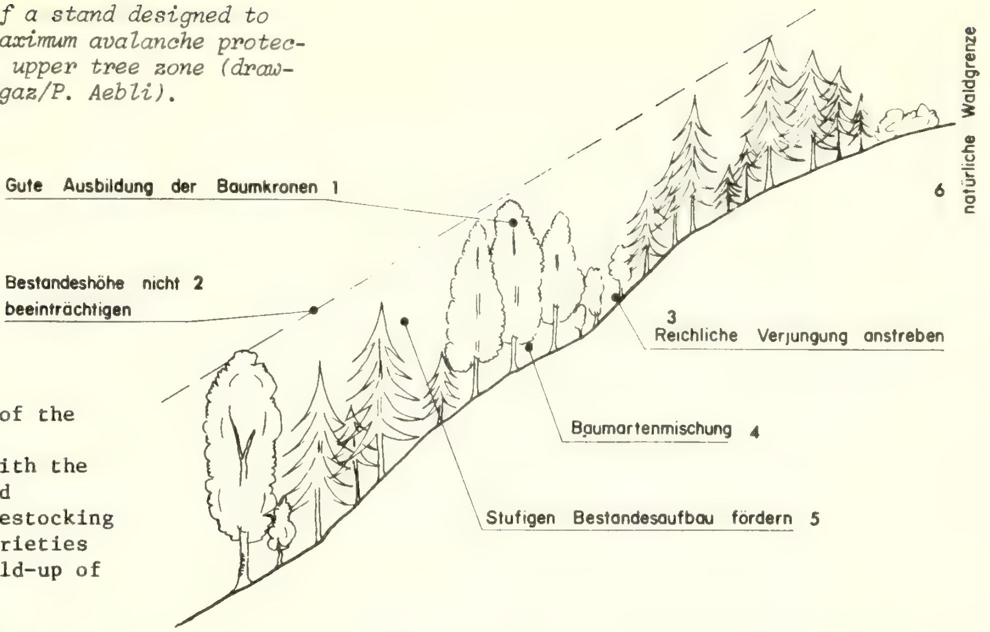
In overaged, frequently single-stratum larch grazing forests, it is indispensable to cultivate in a checkerboard arrangement in order to conserve the stock. As long as there is no control of grazing, a fence is indispensable.

The forest structural measures described and suggested have have one thing in common. They must be planned very carefully and over a long period of time. Wrong decisions can entail catastrophic results in the battle zone [upper zone] of forest vegetation, and these results can often be corrected only by elaborate means.

5. Conclusion

The conservation and extension of mountain forests implies an effective protection of the environment for the alpine area. Permanent care of these forests is on a par with the laudable efforts which are being made to maintain the purity of water and air. Every hectare of forest guarantees to our settled areas, our transportation routes, and our valuable cultivated lands, the greatest possible protection against avalanches and other forces of nature, at the least cost.

Figure 3. Structure of a stand designed to achieve a maximum avalanche protection in the upper tree zone (drawing: C. Ragaz/P. Aebli).


Gute Ausbildung der Baumkronen 1
Bestandeshöhe nicht 2 beeinträchtigen
3 Reichliche Verjungung anstreben
Baumartenmischung 4
Stufigen Bestandesaufbau fördern 5
6
natürliche Waldgrenze

Key:

1. Good conformation of the tree crowns
2. Do not interfere with the height of the stand
3. Strive for ample restocking
4. Mixture of tree varieties
5. Promote graded build-up of the stand
6. Normal timberline

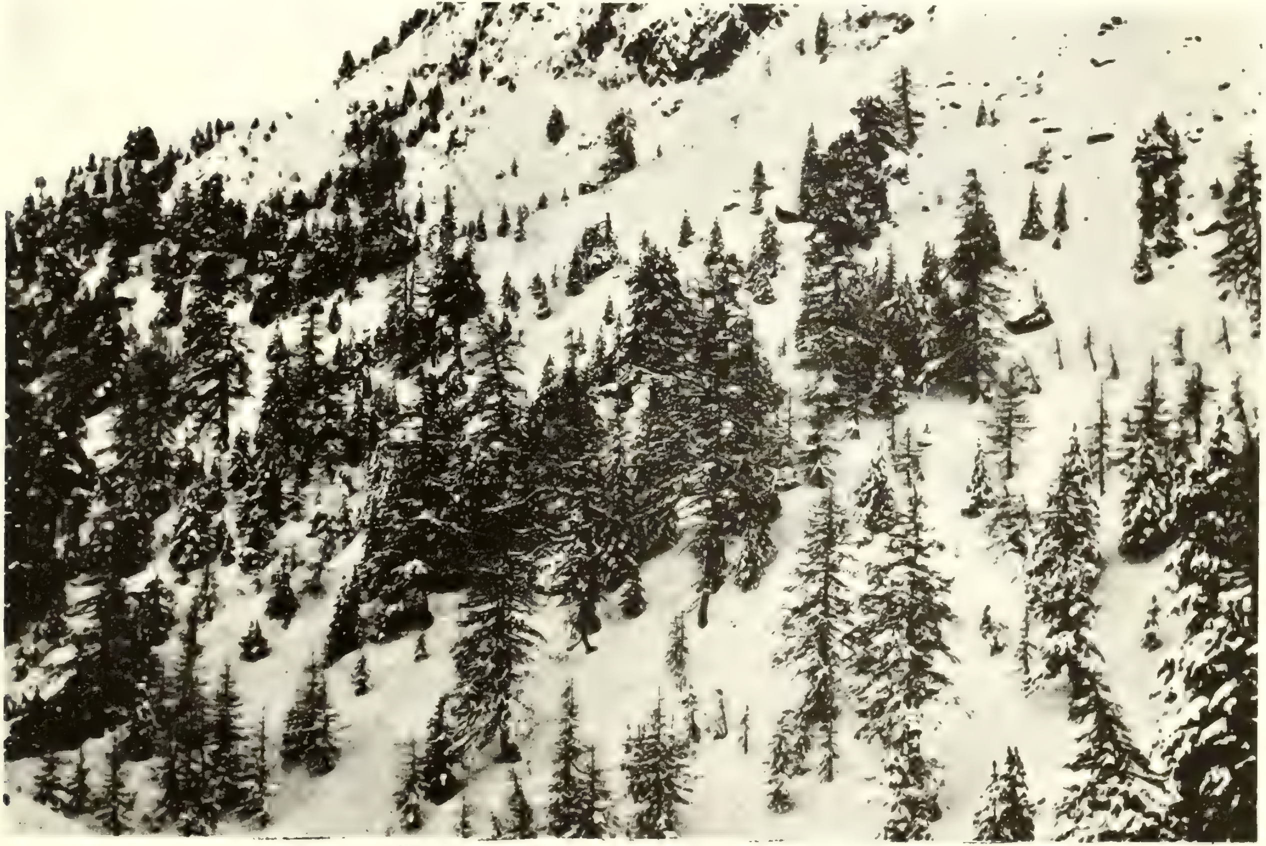


Figure 4. A larch-Cembran pine forest in process of developing at the upper tree line. It is already capable of a favorable effect upon the snow cover conformation and guarantees protection to the stand below (photo C. Ragaz).

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English Translation of German Titles

[1] Protective Functions of the Forest in the Mountains.
[2] The Protective and Recreational Effects of the Forest.
[3] The Avalanches of the Swiss Alps.
[4] The Effect of the Forest on the Water Balance.
[5] Regeneration in the Region of the Upper Tree Line.
[6] Flowering Plants in the Battle With Winter.
[7] The Role of the Forest in Avalanche Protection.
[8] Afforestations and Structural Control in the Upper Engadine 1875-1934.
[9] Afforestations at High Elevations.
[10] Microclimatography and Its Use in the Ecology of the Subalpine Zone.
[11] Afforestation Experiments on a Gliding Snow Slope.

OUTLOOK (Maurice de Coulon, Bern)

In the year 2000, Switzerland will have a population of from 7 to 8 million, and toward the middle of the 21st century, there will probably be several million more. Our grandchildren will perhaps work only 3 or 4 days in a week, have much longer vacations, and retire at the age of 55 at the latest. (Some will say that this is impossible for agriculture; but will mountain agriculture continue to exist at all at that time as a sector of the economy?)

More than 90 percent of the population lives today in the flat areas and has settled only a third of the country. A large part of the center of the country is already overpopulated. Even if Switzerland remains a political enclave, it will sooner or later have to integrate economically with Europe. Today people no longer pay attention to national boundaries in selecting their vacations.

Will not the alpine area in the future become to an even greater degree an attraction and a recreation area for millions of Europeans having ever more free time at their disposal both summer and winter? The beautiful landscape, tranquility, and clean air -- rare good things -- will they not be wanted in increasing measure?

In order to effectively form the development of the mountain region, this development should be much better planned and coordinated than hitherto. It is of first importance that regions should be delimited and then reference models and development plans should be worked out in accordance with which the local planning can regulate itself. (A political division, which often does not have functional boundaries can, as a rule, not be viewed as a planning unit.)

The avalanche zones form -- as is the case with all danger zones -- fixed points for space planning in the mountains. They exclude development or they limit it sharply and are hence, as a rule, segregated without compensation in the form of green zones.

The avalanche construction projects, like landscape protection and the recreation facilities, will form an integrating constituent of regional planning. As befits contemporary politics, it is of primary importance for existing residential settlements and transportation facilities to be protected from avalanches. New building land should be designated with restraint and only outside avalanche zones. The responsible authorities in this way prevent scattered settlements, reduce outlays for community facilities, and control land speculation. The investments for avalanche control constructions, in order of urgency, should be used at the locations determined by the regional planning. Avalanche construction everywhere and at any price -- for the Federal Government at any rate -- is out of the question. The funds available must not be squandered.

As a rule, before working out avalanche construction projects, it is necessary to collect socioeconomic statistics. The production of the control constructions usually requires years and often decades of labor. How will the population and the economy of the region develop in the meantime? There are limiting cases in which the suitability of certain measures is extremely questionable.

In the study of control construction projects, in future increased weight must be placed upon the evaluation of the various protective possibilities and upon checking the technical, social, and especially financial advantages and disadvantages of each variant. The decision does not lie only with the technologist: the requirements of safety and those of the national economy must be adapted to one another. How far can one go with investments for control constructions? To be sure a human life is more valuable than the most expensive avalanche control project. But can an expenditure of millions for the protection of one or two houses be justified when these houses are worth only a fraction of the construction costs? Wouldn't it often be much simpler to resettle a few people instead of carrying out difficult and expensive projects for defense against avalanches?

In studying different variants of a project, the required minimal protective function must remain the criterion. The ratio of the funds expended (input) to the result achieved (output), depending upon the variant, will turn out very differently. In general, the costs are relatively easy to estimate; in contrast, the evaluation of social utility is much more difficult, especially when one attempts to compare the different variants quantitatively (cost-use ratio; profitableness). To the extent that such estimates are possible at all, one will have to be content with approximate values and orders of magnitude. Be that as it may, the costs must, in each individual case, be established in detail and their ratio to the desired protective function must be examined (e.g., cost per person or building or per hectare of ground surface to be protected). A preliminary cost estimate cannot be justified by multiplying the length of the installation by the unit price.

In checking out the different variants, preference will be given to the one which at about the same cost has the most advantages or which for approximately the same advantages represents the cheapest solution. This variant will be of decisive importance for the project design. Only now is the detailed study begun.

In the regions of avalanche fracture, the forest -- wherever there is any possibility at all of establishing and maintaining one -- is without doubt the safest, most durable, and cheapest protective arrangement. In contrast to control construction it fits harmoniously into the landscape and at the same time performs manifold functions. Hence, the forest must be maintained in the highlands and restored where necessary; at the same time priority must be given to the afforestation of slopes exposed to avalanche risk. When the mountain forest is properly cared for, it usually restocks itself; in many places the natural restocking also extends to idle land. Avalanche construction projects can be viewed as an extension and a supplementation of forestry: hence, the forest ranger will be concerned with these projects in additional respects.

The cantons and especially the Federal Government guarantee very high contributions to avalanche construction projects. Thanks to the new investment credits such operations can be completely financed. It is justifiable to continue this supportive politics in the public interest also in the future, but the funds must be employed with more refinement and more purposefully. What criteria are decisive for determining the rate of contribution? What significance, what weight is to be attributed to these criteria? Will the Federal Government reach the point of regulating its contributions in accordance with the interests which the general public have in the enterprise concerned (increased contribution for constructions of national and regional interest, as in the protection of natural features)? Is it in every instance justifiable that the builders, who are primarily interested in the construction, should bear only a small fraction of the costs? It probably goes without saying that in the future, too, the Federal Government will examine projects very carefully, quite particularly with regard to their significance and reasonableness within the context of regional planning. A project which justifies itself only from the engineering point of view is only half a project.

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